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Analysis of Waste Sector Projects and Methods

DELIVERABLE 2:
Performance of the landfill gas method against the offsets integrity standards

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ABBREVIATIONS AND ACRONYMS

Abbreviation/ Acronym	Description
ACCU	Australian Carbon Credit Unit
BPEM	Best Practice Environmental Management
CDM	Clean Development Mechanism
CH_4	Chemical formula for Methane
CFI Act	The *Carbon Credits (Carbon Farming Initiative) Act 2011*
CFI Methodology Determination	See Methodology
DE	(Methane) Destruction Efficiency
DOC	Degradable Organic Carbon
DoEE	Department of the Environment and Energy
Eff	Electrical efficiency factor
EPA	Environmental Protection Agency
ERF	Emissions Reduction Fund
EU	European Union
GGAS	NSW Greenhouse Gas Reduction Scheme
GHD	GHD Australia Pty Ltd
GHG	Greenhouse Gas
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
kW	Kilowatt
kWh	Kilowatt hour
Landfill gas method	See Methodology
LCA	Life Cycle Analysis
LFG	Landfill gas
LGC	Large-scale generation certificates
Method	See Methodology
Methodology	Either: *Carbon Credits (Carbon Farming Initiative—Landfill Gas) Methodology Determination 2012*, or *Carbon Credits (Carbon Farming Initiative—Landfill Gas) Methodology Determination 2015* If not specified, assume the current 2015 version of the Methodology is meant
MWe	Megawatt electric
MWh	Megawatt hour
NCT	Non-Carbon Tax
NGER Act	The *National Greenhouse and Energy Reporting Act 2007*

Abbreviation/ Acronym	Description
NGER (Measurement) Determination	The National Greenhouse and Energy Reporting (Measurement) Determination 2008
POEO	Protection of the Environment Operations
ppm	parts per million
Regulation	The Carbon Credits (Carbon Farming Initiative) Regulations 2011
Resource Intelligence	Resource Intelligence Pty Ltd
RET	Renewable Energy Target
SMEC	SMEC Australia Pty Ltd
UNFCCC	United Nations Framework Convention on Climate Change
WMAA	Waste Management Association of Australia

EXCECUTIVE SUMMARY

To be provided in Final.

Conclusions Summary

Table 1 provides a summary of the conclusions made.

Table 1: Conclusions Summary

No.	Conclusions
Conclusion 1	The additionality tests exclude non-additional abatement where practicable. The most important factor for the landfill gas Methodology in excluding non-additional abatement is the use of an appropriate baseline.
Conclusion 2	The default methane percentage of 50% can be used for extended periods when the actual methane percentage may be materially lower. For example, if a site claims 50% but the actual methane concentration is 40%, then the claimed units would be 25% higher than actual gas destruction
Conclusion 3	Tighter (i.e. lower) landfill gas action levels in Victoria (and the ACT) create a higher Regulatory Proportion, modelled as 52%-88% depending on the landfill size. As such, in these cases, the Regulatory Proportion is higher than the default baseline of 30%. Consequently, the Regulatory proportion needs to be selected as the site's baseline.
Conclusion 4	The current Methodology approach to calculating abatement seems appropriate. It is noted that the default baseline of 30% was negotiated between the government and the industry in 2011. There has not been a subsequent operational data and re-calculation will require a more thorough investigation. It is expected that, the geographical location (given the organic decomposition rates, and hence the landfill gas generation rates) to be considered, amongst others.
Conclusion 5	The establishment of most landfill gas collection systems correlates with the introduction of financial incentives from the creation of GHG emissions abatement and/or the generation of electricity. Gas collection in 2015 was 2.5 times (8,070 ktCO2-e in 2015 versus 3,210 ktCO2-e in 2002) that before incentives (beyond the value of electricity) were introduced in 2003. These incentives appear to drive and maintain investment in landfill gas collection. Without them, investment is likely to commence later in the lifecycle of cells and be lower, leading to collection rates declining in existing projects. This conclusion is more certain in relation to landfill gas flaring but also applies to energy generation projects.
Conclusion 6	Legislative or regulatory requirements specifically requiring landfill gas capture at landfills relate primarily to risk management activities (e.g. odour, toxicity and explosion risk), rather than GHG emissions abatement activities. Management tools other than collection/flaring, such as better capping materials, could achieve legislative compliance but at a lesser rate of GHG emissions abatement.

No.	Conclusions
Conclusion 7	Landfill gas capture is mentioned in State and Territory guidelines on appropriate landfill management. Nevertheless, these guidelines focus on potential environmental and health and safety risks such as; methane concentrations at the boundary of the site, odour and potential impact on receptors and potential gas migration pathways. Landfill gas combustion seems to be the most effective (and given the financial incentives), the most economical means to address these requirements. Nevertheless, landfill sites might implement other activities (refer to section 2.4.1.1) that will result in compliance with the guidelines without the abatement of GHG emissions.
Conclusion 8	Landfill licences vary across States and within States (e.g. depending on the landfill size) and are applicable to individual sites. Some landfill licences do require landfill gas capture and management. Despite the requirement being intended to mitigate potential risks, these requirements result in GHG emissions mitigation. It is noted that because these requirements don't specify the extent of (i.e. how much gas) landfill gas that must be managed (e.g. captured and combusted), these requirements account for the 30% qualitative baseline in the Methodology.
Conclusion 9	The existing baseline arrangements in the Methodology may represent a barrier, particularly for potential projects in Victoria where a lower maximum parts-per-million (ppm) of methane concentration above the surface of the landfill, can result in a baseline greater than the default 30%.
Conclusion 10	The non-carbon tax emissions calculation requirement may present a barrier, particularly for small landfills which do not need to carry out this calculation for NGER reporting.
Conclusion 11	The baseline determination is the major reflection of additionality for a landfill gas project. The current default baseline of 30% was evaluated in 2011. Data from projects in operation since then could be used to develop new baselines, particularly to determine additionality levels upon entering an extension period.
Conclusion 12	The continuous cell development process in landfills, means that ongoing investment is required if gas capture and management is to be maintained. If financial incentives such as from the creation of ACCUs and electricity generation (as applicable) are not available, gas collection and management may decline.
Conclusion 13	The baseline abatement can be quantified using the calculation approaches set out in equations 12 to 19 of the Methodology. To assess this the equations in the Methodology (summarised in Figure 8) have been reviewed and allow quantification. The Methodology, explanatory statement, and guidance are sufficient for this to be calculated and verified.
Conclusion 14	By conducting a detailed review of all of the equations and parameters in the 2015 Methodology (summarised in Table 11), it is clear that the abatement delivered by eligible projects can be quantified using the calculation approaches set out in the Methodology. Net abatement in the Methodology is fully verifiable if the equations have been worked out correctly and the supporting data for each parameter is available.

No.	Conclusions
Conclusion 15	Abatement delivered by eligible projects can be quantified using the calculation approaches set out in the Methodology. This is dependent on the project proponent collecting and appropriately applying the required data. This conclusion is supported by reviewing all the equations and parameters required in the Methodology. As such, the following is confirmed: The calculation approaches are straightforward and mathematically robust. The net abatement calculations are an accurate representation of reality. The Methodology focused on direct measurement of the key parameters that determine the ACCUs (i.e. the quantity of methane sent to (and destroyed by) the combustion device h). The 2012 and 2015 Methodologies will yield approximately the same output if the same options (e.g. selecting the default, not measurement data) are selected. However, the two Methodologies differ in the circumstances in which different options may be selected and have slightly different system boundaries and parameter requirements. Nonetheless if the project proponent follows the equations outlined in the Methodology the net abatement can be accurately calculated. The calculated abatement is fully verifiable if the project proponent has followed the requirements for monitor, measurement and data collection (as assessed in section 3.2)
Conclusion 16	Measuring requirements are defined as being consistent either with NGER (Measurement) Determination specifications or with estimates or relevant standards and other requirements under the National Measurement Act 1960. This is considered to be scientifically and technically robust as Australian Standards must be adhered to. The Methodology clearly specifies these requirements and makes references to external sources in an accurate and appropriate way.
Conclusion 17	As the 2015 Methodology does not clearly specify the data collection requirements it can be concluded that they are not adequately specified.
Conclusion 18	There are some differences and similarities between the 2012 and 2015 Methodologies. The areas of least rigour are: a) The ability to use a default concentration of 50% (if measurement not already in use in the 2015 Methodology, and at any time in the 2012 Methodology). b) Electrical efficiency can vary between different engine types, how well they are operated and maintained, and the load factor at which they are operated. All engines would be expected to have a technical specification. Therefore, it is not clear why the use of a default value of 36% would be appropriate. c) Instruments must be calibrated to manufacturer specifications. Nevertheless, manufacturers generally do not specify calibration frequency for flow, temperature and pressure instruments. Furthermore, specifications may not be fully valid for landfill gas conditions (landfill gas can be moist, contain dirt particles and microbiological content).

No.	Conclusions
Conclusion 19	The calculations set out in both the 2012 and 2015 Methodology allow the abatement delivered by the project to be quantified through the use of scientific measurements. Equations used vary depending on the project type so the use of calculations is tailored to different projects. The volume of landfill gas sent to a destruction device is measured by robust scientifically based devices. The process of then converting landfill gas to volume of methane and amount of methane destroyed is also robust as this uses common methods for destruction efficiency. This excepts the use of some of the default values. In general, the default values are conservative and do not have a material influence on calculated abatement.
Conclusion 20	The Methodologies clearly set out the equations and how these should be applied to quantify the volume of landfill gas sent to destruction devices.
Conclusion 21	By reviewing the Methodologies, it can be concluded that the measurement and monitoring requirements refer to external references where appropriate and required.
Conclusion 22	The Methodology has taken reasonable steps to minimise uncertainty in measurement and data collection. Most measurement requirements are relatively straightforward and reduce uncertainty (e.g., gas flow measurements need to be within strict uncertainty limits). With the measurement of gas flow and methane concentration there is some inherent uncertainty as specified by manufacturer measurement devices.
Conclusion 23	The 2015 Methodology reporting requirements are not clearly specified, for example it does not state that the abatement calculations, parameters, and data sources need to be included in the offsets report. It is therefore recommended that these are more clearly specified so that projects know what level of detail is required, and so there is a more standardised and common approach to reporting. Of the projects reviewed there is an apparent variability in reporting, this supports the conclusion that the reporting requirements are not clearly specified.
Conclusion 24	There is a risk with the 2015 Methodology that, as the reporting requirements are limited, not all the information would be required to be kept under the record-keeping requirements (i.e. sections 192 and 193 of the CFI Act require records to be kept if this is used in preparing the offsets report). If the offsets report does not specify much detail, then it is possible that the project proponent may not retain all the required information necessary to demonstrate compliance with the Methodology. This is a potential issue when it comes to the verification of methodology compliance.
Conclusion 25	Record keeping requirements in the 2015 Methodology do not include all information required to demonstrate compliance with the Methodology in full. As the auditor is verifying compliance with the whole Methodology the record keeping requirements could be specified in additional detail to assist with the verification process.

No.	Conclusions
Conclusion 26	Record-keeping requirements, as defined in the CFI Act, require project proponents to retain records if they are used in the preparation of the offsets report. There are some gaps in the specific detail to be included in offsets reports that could lead to required information not being recorded. Furthermore, if the reporting and record-keeping requirements do not cover all aspects of the Methodology, then it could be difficult for an auditor to verify that all requirements in the Methodology have been met.
Conclusion 27	In the 2015 Methodology, the abatement calculations should be verifiable (i.e. the project must provide the required data to support each parameter and assumption used in the equations). However, the record keeping requirements (when compared to the 2012 Methodology) are very limited in detail and do not explicitly specify the records that must be kept. In contrast, section 4.4 of the 2012 Methodology is very specific in the record keeping requirements. As such, the 2012 Methodology is more straightforward to verify than the 2015 Methodology.
Conclusion 28	There are differences between the 2012 and 2015 Methodologies regarding the record keeping requirements. The 2012 Methodology has relatively detailed and specific record keeping requirements which potentially reduce the flexibility in the type of evidence available to proponents. However, this is likely to make the verification process more straightforward. Contrastingly, the 2015 Methodology has limited record-keeping requirements, which increases the flexibility in evidence requirements, but can potentially create more issues in the verification process.
Conclusion 29	There are not many aspects of the CFI Methodology Determination where the type of evidence has much flexibility, i.e., equipment and instrument data obtained from the monitored parameters is likely to only be derived from one source. Hence, whilst there could be some flexibility, the methods are prescriptive in the data that is required for the abatement calculations.
Conclusion 30	There are no apparent projections used under the landfill gas Methodology as it is reliant on direct measurement and calculations. When compared to other CFI/ERF methods (other than previously discussed estimations/assumptions) the landfill gas Methodology is considered to use appropriate and conservative values. Furthermore, wherever practical, these are aligned with NGER (Measurement) Determination methods which also compare to other international methods such as those adopted by the CDM.
Conclusion 31	In terms of whether the 30 per cent default regulatory proportion defined in section 28 of the Methodology is supported by clear and convincing evidence, the authors of this report have not been able to assess all the source of information that underpin that statistic. Nevertheless, the input parameters (which are available) appear to be appropriate.
Conclusion 33	The data obtained shows a trend that bigger landfills have higher emissions which would be expected. However bigger landfills also tend to capture more of the landfill gas so the emissions per tonne of waste received is in general lower for larger landfills.
Conclusion 34	Data on landfill tonnes per annum can be very difficult to obtain in the public domain. For some landfills, it was possible to obtain this data from literature searches, however whilst all sites were searched for it is apparent that this information is not readily available. It is therefore recommended that the state and federal Governments try to collate this information together so it is more available.

No.	Conclusions
Conclusion 35	Scope 1 GHG emissions data for landfills provided by the CER highlights some issues in this data collection and quality. For instance, there are a significant number of facilities that have only reported for one year, not all years, or stop reporting altogether. There could be valid reasons for this such as being below a reporting threshold, change of name, data missing, etc. however it would be expected that landfills should have relatively consistent emissions profiles year on year so some further investigation into the scope 1 emissions reported under NGER or State Governments should be undertaken.
Conclusion 36	For ERF projects the waste received at a landfill (split by waste type / composition) is required for calculated abatement. It would be useful if the CER or DoEE collated this information so further analysis can be performed of different landfill characteristics.
Conclusion 37	Key factors affecting the proportion of maximum possible gas collection are depth, width, type of waste, leachate issues, how hot the climate is, how wet the climate is, type of cap, type of lining, how well the landfill is managed in general. The NGER Measurement Determination assumes that a maximum 75% of gas generated can be collected; actual practice anecdotally and from literature varies from zero (no collection) to under 50% for poorly managed sites to nearly 100% at sites with the most effective collection management. Note that the percentage of gas collection is not a factor considered in the 2012 or 2015 Methodologies; crediting is on the basis of tons of methane above the baseline amount oxidised.
Conclusion 38	For a landfill gas capture, flare and power generation system, over the life of asset considered (seven years), the capital costs represent 50% of the costs and the ongoing costs (e.g. operation and maintenance) represent approximately 30% of the total costs and the power generation overhaul represent approximately 20% of the total costs. For a landfill gas capture and flaring system, these costs would be 41% for the capital costs and 59% for the ongoing costs. This is mainly due to the operation and maintenance requirements of the landfill gas capturing system.
Conclusion 39	ACCUs are a strong incentive for power generating projects. In consideration of the life of asset (seven years), the ACCUs contribute to achieving revenue from both the power generation project and the landfill gas capture and flare project. Nevertheless, without the ACCUs and in consideration of the revenue streams from the sale of electricity for applicable projects, these projects may present a loss over the life of asset.

PERFORMANCE OF THE LANDFILL GAS METHOD AGAINST THE OFFSETS INTEGRITY STANDARDS

This report addresses the following requirements:

- Requirement 2: Assessment of whether carbon abatement supported by the method is unlikely to occur in the ordinary course of events (section 2);
- Requirement 3: Assessment of whether the emissions removal or reduction, as the case may be, are measurable and capable of being verified (section 3);
- Requirement 4: Assessment of whether the method is supported by clear and convincing evidence (section 4);
- Requirement 5: Assessment of whether estimates, projections or assumptions are conservative (section 5); and
- Requirement 6: Provide data and an analysis of landfill gas capture and combustion projects (section 6).

2 Assessment of whether carbon abatement supported by the method is unlikely to occur in the ordinary course of events

2.1 Whether foreseeable activities or circumstances that would be likely to result in non-additional abatement are excluded, where practicable.

Section 27(4A) of the *Carbon Credits (Carbon Farming Initiative) Act 2011* (CFI Act) sets out three tests for additionality:

- The newness requirement (section 2.1.1);
- The government program requirement (section 2.1.2); and
- The regulatory additionality requirement (section 2.1.3).

The three tests, as stated in the CFI Act, exclude non-additional abatement from being credited with Australian Carbon Credit Units (ACCUs). However, the additionality tests are adjusted for some Methodologies. The CFI Act provides for caveats for each of the three tests that allow either Carbon Credits (Carbon Farming Initiative - Landfill Gas) Methodology Determination 2015 (the Methodology) or legislative rules to specify other requirements that can be used in lieu of, or in addition to, the stated additionality tests.

2.1.1 Newness test caveat for landfill gas

There is a caveat for the newness requirement in the landfill gas Methodology. This applies to a small class of recommencing landfill gas projects which have been inactive for over three years. The newness caveat is included to encourage operators to reinvigorate old landfill gas systems that are no longer operational.

It appears unlikely that a landfill would stop operating a landfill gas system for three years solely to subsequently create ACCUs. This is because operators of most reasonable sized landfill gas systems would not be easily able to stop operations for three years due to:

- risk management focus regulatory requirements (section 2.4),
- equipment deterioration and associated costs (sections 2.3.1 and 6.3), and
- potential community concerns over odour.

The newness caveat is therefore considered to exclude non-additional abatement.

2.1.2 Government program requirement caveat

There is no government program requirement caveat for the landfill gas Methodology. All landfill gas projects meet the CFI Act's government program additionality requirement. That is, if a landfill gas system is new and it is not being supported by another Government program, it receives accreditation under the landfill gas Methodology by the fact that it is a landfill gas project.

2.1.3 Regulatory additionality caveat for landfill gas

The material caveat for the landfill gas Methodology is the requirement in lieu of regulatory additionality that *if the project is a landfill gas project it passes the regulatory additionality test*. To manage the regulatory additionality test, *baselines* are applied to exclude non-additional abatement (i.e., a landfill gas project does not receive ACCUs for all the methane it destroys). The baseline reduces the number of ACCUs the project receives based on the amount of gas that would have had to be captured for regulatory purposes had the project not been accredited under the Emissions Reduction Fund (ERF).

Example:

If a project has a 30% baseline, and destroys 100 t CO_2-e of landfill gas in a reporting period, the project will receive credit for only 70 t CO_2-e of methane destruction, because the baseline assumes 30 t CO_2-e would have been destroyed anyway because of regulatory requirements.

Conclusion 1 The additionality tests exclude non-additional abatement where practicable. The most important factor for the landfill gas Methodology in excluding non-additional abatement is the use of an appropriate baseline.

The application of the baseline forms part of the *regulatory additionality test*. It determines how many ACCUs can be created, based on how much gas would need to be captured to meet regulatory requirements. It is noted that it is not possible to capture all gas emitted from a landfill. Regulatory requirements for gas capture vary greatly between jurisdictions and between sites. Figure 1 provides information on the variety of mechanisms each state and territory use to regulate and guide landfills.

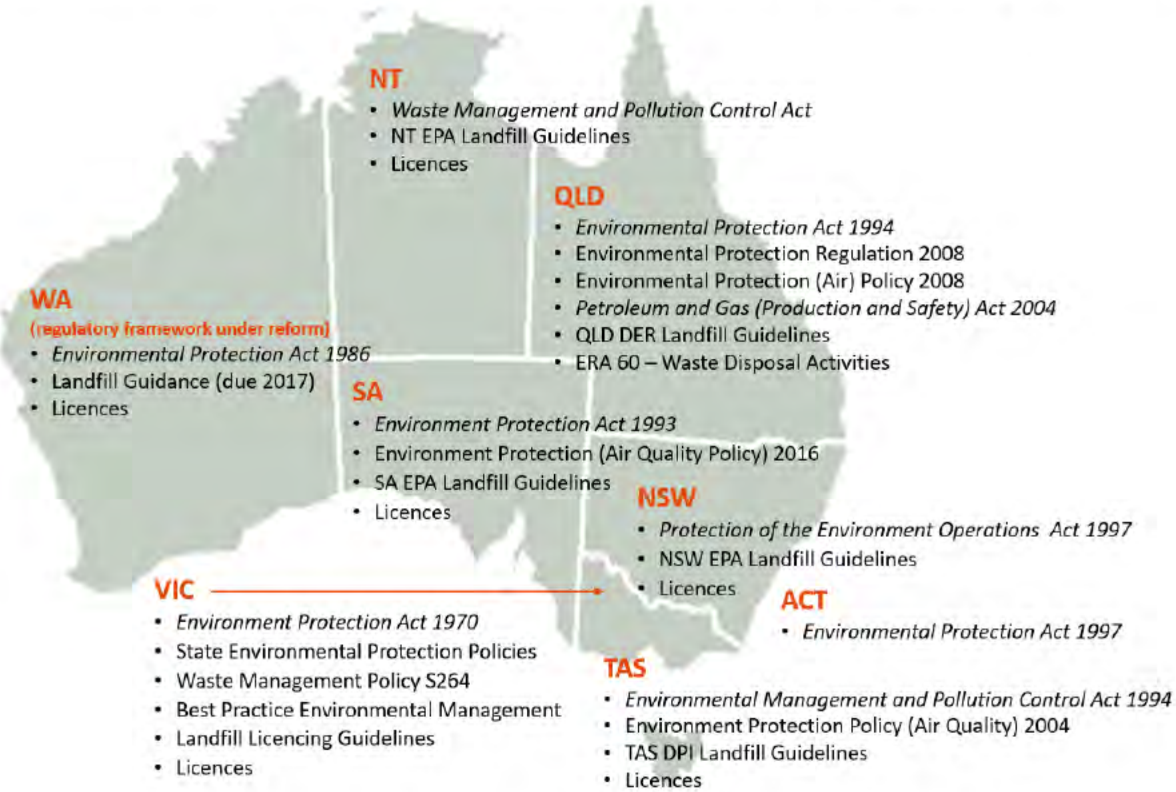

Figure 1: State and Territories waste regulatory framework and requirements

The principal reasons for regulatory requirements to capture gas include the management of risks associated with pollution, occupational health and safety, odour, and importantly for this report, in some cases, greenhouse gas (GHG) emissions minimisation. This is examined in more detail in section 2.4.

2.2 Whether the approach to calculating abatement—including the calculation of baselines and the use of discounts and other adjustments—results in the crediting of abatement that is unlikely to occur in the ordinary course of events.

Summary:

When the baseline and other default factors needed to be determined in 2011 there was less information and data available. Most of the baseline and default factors currently used are deemed appropriate. A review could be undertaken of the 30% default baseline, the use of a default 50% methane concentration, and the Non-Carbon Tax reduction.

The overall approach of calculating abatement by following and applying the 22 sequential equations in the Methodology seems robust and is generally consistent with international landfill gas carbon credit methods. The material default variables and measurements within the landfill gas Methodology are:

- Default Factors (section 2.2.1):
  - Default methane percentage.
  - Destruction efficiency of flares and engines.
  - Global warming potential (GWP) of methane.
  - Energy content of landfill gas.
  - Oxidation factor.
  - Electrical efficiency of engines (for electricity generation).
- Measurement Methods (section 2.2.2):
  - Measurement of methane sent to a combustion device.
  - Measurement of energy content of landfill gas sent to combustion device.
  - Measurement of electricity produced by a landfill gas engine.
- Non-carbon tax waste percentage (section 2.2.3).
- Baseline (section 2.2.4).

2.2.1 Default factors

2.2.1.1 Default methane percentage

The default methane percentage is set at 50%. This represents a reasonable and conservative average estimate, but it is possible to operate a flare with methane concentrations lower than 40%. Low methane concentrations can occur, particularly towards the end of the methane generation cycle from a waste body. Gas composition analysers are widely used in landfill gas collection systems, and may be used in ERF projects, but are not compulsory. Once a project has used measurement it must continue to do so under section 24(3) of the current (2015) Methodology, but if the project commences using the default value it can continue to be used indefinitely. Projects still using the 2012 Methodology can change to and from the default factor as they wish.

There is an unquantified risk of 'gaming', where projects measure concentration only where it is financially advantageous to do so. It was not possible to assess the likelihood of gaming, but detailed assessment of a project's methane percentage and the use of default factors (if available) could provide some insight on the potential methane overestimation.

For example, if the default methane percentage of 50% is used, when gas samples indicate an actual concentration of, say, 40%, then the claimed units would be 25% higher than actual gas destruction.

A high-level literature review was performed to determine the minimum methane percentage a flare and a power generation engine can operate. The findings are provided below.

2.2.1.2 Minimum methane percentage - flaring

Parker et al 2002[1] indicate that the minimum volume concentration of methane for flaring is 20% (i.e. this concentration enables the landfill gas to form a combustible mixture with ambient air). As such, at 20% methane, only the landfill gas is needed for the flare operation. At landfills with methane concentration of less than 20%, supplemental fuel (e.g. natural gas) is required to operate flares. It is noted that in the industry, based on Australian conditions and depending on the equipment and moisture levels of the gas, the minimum methane percentage required to operate a flare is believed to be underneath 40%. The preference is to operate above 40%.

2.2.1.3 Minimum methane percentage – power generation

Performance of the electricity generation engine operated with landfill gas significantly depends on:

- the methane concentration on the landfill gas; and
- impurities in the landfill gas (i.e. hydrogen sulphide, chlorinated and fluorinated compounds cause corrosion of the engine parts and decrease life of the engine oils).

Literature indicates that the presence of high level of impurities reduce the economic viability of energy recovery[2]. Furthermore, minimum methane concentration required for an engine to work was found to be as low as 35% in the landfill gas[3]. It is noted that this concentration was recorded by an engine manufacturer and does appear to be too low for the industry. Other source[4] reports that the methane concentration, evaluated by field measurements at 3 landfill sites, ranged from 41% up to 98%.

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[1] Parker, T., Dottridge, J. and Kelly, S., (2002) Investigation of the composition and emissions of trace components in landfill gas. Environment Agency, R&D Technical Report P1-438/TR. Accessed 29/08/2017, retrieved from: http://gassim.co.uk/documents/P1-438-TR%20Composition%20of%20Trace%20Components%20in%20LFG.pdf

[2] Sevimoğlu, O. and Tansel, B., (2013) Effect of persistent trace compounds in landfill gas on engine performance during energy recovery: a case study. Waste management, 33(1), pp.74-80.

[3] Ibid. p. 80.

[4] Spokas, K., Bogner, J., Chanton, J.P., Morcet, M., Aran, C., Graff, C., Moreau-Le Golvan, Y. and Hebe, I., (2006) Methane mass balance at three landfill sites: What is the efficiency of capture by gas collection systems?, Waste management, 26(5), pp.516-525 in Di Maria, F., Sordi, A. and Micale, C., (2013) Experimental and life cycle assessment analysis of gas emission from mechanically–biologically pretreated waste in a landfill with energy recovery. Waste Management, 33(11), pp.2557-2567

Conclusion 2 The default methane percentage of 50% can be used for extended periods when the actual methane percentage may be materially lower. For example, if a site claims 50% but the actual methane concentration is 40%, then the claimed units would be 25% higher than actual gas destruction.

2.2.1.4 Oxidation factor

The oxidation factor of 10% is dealt with in detail in section 4.1.5.4.

2.2.1.5 Other default factors

The other five default factors listed above generally follow international guidelines or NGER Act determinations and are considered appropriate. For example, the default methane destruction efficiency for a combustion device[5] of 0.98 is based on the use of an enclosed flare, which is the most usual arrangement for safety and control reasons. The default methane destruction efficiency for an internal combustion engine device of 1.00 appears reasonable for large internal combustion engines such as electricity generators.

2.2.2 Measurement methods

Section 24 of the Methodology provides three options to quantify the methane destroyed. The three measurement options are;

- Option 1 – using landfill gas sent to a combustion device;
- Option 2 – using energy content of landfill gas sent to combustion device; and
- Option 3 – using electricity produced by internal combustion engine.

The three options follow robust techniques that have precedent set in other internationally recognised landfill gas carbon credit methodologies and apply a robust metering solution.

It is noted that Option 1 provides two ways to determine the methane percentage to be considered, which are:

a) As set out in section 5.14C of the NGER (Measurement) Determination (i.e. the default method, which estimates the methane concentration to be 50%,); or
b) worked out in accordance with the monitoring requirements (i.e. the measurement method).

The effect of this is discussed in section 2.2.1.1.

2.2.3 Non-Carbon Tax percentage

In the context of the landfill gas Methodology, it is unclear why emissions from waste deposited during the carbon tax years should be excluded. Emissions of landfill gas start a year after waste deposit and continue for occur over a long period, based on the model set by the NGER (Measurement) Determination. Based on this Methodology, in, for example, a Victorian landfill that accepted an equal quantity of waste during the carbon tax years, only 2.3% of the emissions would have arisen during those years. Therefore, 97.7% of the emissions arising subsequently in an offsets-reporting period should be considered non-additional. More detail on the non-carbon tax is provided in section 2.5.2.

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[5] Parameter "DE" in Equation 7 of the Methodology.

Under the carbon tax, many landfill facility operators charged their customers in relation to future carbon liabilities that were expected to accrue as the waste being deposited decayed over many decades. With repeal of the tax, future tax liabilities for emissions from that waste will not eventuate, although charges equivalent to those future year liabilities were paid by many waste customers.

2.2.4 Baselines

Different landfill gas projects may receive different baselines. The baseline applied to a project is the main factor when assessing the risk of under- or over-crediting. If a baseline is too high, a project would not be credited ACCUs for abatement additional to regulatory requirements, and may mean the project does not go ahead. By contrast, if a baseline is too low, a project will receive ACCUs for abatement that would have occurred regardless because of regulatory requirements.

Section 28 of the Methodology sets a baseline for new or recommencing projects, equal to the greater of the regulatory proportion or a default value. It is noted that projects that transitioned from the Greenhouse Friendly program and the NSW Greenhouse Gas Reduction Scheme (GGAS) were allowed to maintain their original baselines.

2.2.4.1 The regulatory proportion

The regulatory proportion is calculated with reference to Schedule 1 of the Methodology, which provides four options:

1. Reference to State or Territory guidelines for landfilling, which are interpreted as setting limits for gas concentrations above the landfill. These levels are linked to a percentage gas capture rate through modelling. The modelling links methane generation (calculated using NGER methods) to concentrations above the landfill, using a model based on landfill surface area and the proportions of the surface area under different types of cover.
2. Asking the regulator what gas capture rate is needed to comply.
3. Asking the regulator whether the current gas capture rate is compliant.
4. Determined by an independent expert.

Despite not been able to assess the source of information for option 1, the input assumptions parameters appear to be appropriate.

2.2.4.1.1 Do landfill operators regularly exceed the regulated concentrations of methane?

Interviews with relevant State regulatory authorities were undertaken. SMEC contacted the Victorian EPA regulator who confirmed that landfills in their jurisdiction are required to monitor and report on compliance on a yearly basis. Unfortunately, data on exceedances is not available but suggested to review the landfills' annual performance statements in the EPA Interaction Portal[6]. Additionally, the EPA Victoria provided a list of 69 landfill licences numbers.

[6] Information obtained from the EPA Interaction Portal accessed on 12 September 2017 from: https://portal.epa.vic.gov.au/irj/portal/anonymous?NavigationTarget=ROLES://portal_content/epa_content/epa_roles/epa.vic.gov.au.anonrole/epa.vic.gov.au.searchanon&trans_type=ZAPS

SMEC performed a review of the yearly performance statements (comprising of reports from years 2013 to 2016). The focus was on compliance with licence condition requirement L5. The requirement reads:

> *"You must prevent emissions of landfill gas from exceeding the investigation levels specified in Best Practice Environmental Management, Siting, Design, Operation and Rehabilitation of Landfills (EPA Publication 788)".*

A summary of the yearly compliance is provided in Table 2 and a detailed outline in Appendix G. In summary, only 40% of the landfill sites in Victoria comply with L5 licence condition requirement. Most of the exceedances were noted to be a single instance where readings exceeded the requirements. It was also noted that exceedances were either from methane and / or carbon dioxide.

Table 2: Victorian landfill licences compliance with L5 condition requirement

Compliance with L5 condition requirement	2013	2014	2015	2016
Yes	17	14	15	18
	43%	*35%*	*38%*	*45%*
No	21	25	25	21
	53%	*63%*	*63%*	*53%*
Compliance report not available (for a particular year)	2	1	0	1
	5%	*3%*	*0%*	*3%*
Subtotal compliance report available	40	40	40	40
	58%			
No result for the licence	29	29	29	29
	42%			
Total licences	69	69	69	69

2.2.4.2 The default baseline value

The default baseline value is 0% if the landfill has not been subject to legislation or guidelines for gas collection, and 30% otherwise. It is understood that there are few sites where the 0% baseline has been determined to apply for new projects, so the 30% default baseline generally applies.

In practice, where a State or Territory requires landfill gas management (refer to section 2.4), the extent of landfill gas capture required at a particular site varies widely and depends on:

1. The results of monitoring of gas concentrations above the landfill surface, within monitoring bores, at the site boundaries and/or within underground services close to the site;
2. The distance to the nearest 'sensitive receptors' (e.g., houses);
3. The extent to which odour complaints have been received;
4. The extent of recent rainfall; and
5. The degree of enforcement rigour being applied by the local regulator.

Often gas capture is implemented for the first time as part of an ERF project (or before the ERF; GGAS or an electricity generation project). An analysis of the ERF Project Register on 9 October 2017 shows 19 new and only seven (7) upgrade landfill gas projects.

Large landfills close to highly urbanised areas are at higher risk of giving rise to odour complaints, and are consequently likely to be subject to stricter levels of regulatory enforcement. Wet periods can lead to pulses of gas and odour which are not predicted by NGER modelling. Landfills that are owned by local governments – the norm in regional areas – may be subject to community expectations in terms of odour management so that State enforcement is of secondary consideration.

Because of the inherited variability between sites, the 30% default baseline cannot, in practice, be considered accurate for all sites. However, there is a need for one or more default values.

We are advised by the DoEE that the 30% default baseline was supported by modelling by GHD Australia Pty Ltd (GHD) using relevant values in State and Territory regulations (such as upper limits for methane emission rates from landfill surfaces), and some draft information from that review is available. We are also informed it was also a compromise value agreeable to both the DoEE and the industry. Based on our industry experience, it represents a reasonable and conservative average.

This issue could be investigated at greater depth. It is anticipated that the best way to assess the appropriateness of the 30% regulatory default would be to:

- Compare site gas capture rates (through NGER data) with State and Territory advice on levels of compliance, to the extent this is available. This would highlight the extent of compliance with gas management requirements; or
- Consider the different State and Territory regulatory requirements to determine a State/Territory-specific baseline percentage; or
- Measure the accuracy of a default 30% baseline (i.e. regulatory requirements might represent a different percentage).

2.2.4.3 Case study – why are there few new landfill gas projects in Victoria?

Victoria's best practice environmental management guideline[7] sets default landfill gas action levels (summarised in Table 3). The action level includes 100 ppm methane concentration above the landfill's final cap. This has been interpreted in the Methodology as the basis for the regulatory limit.

The guideline states (p.33) that "EPA need not be advised of an excursion above an action level where only an onsite location was affected and the matter is rectified within 24 hours".

As noted by the DoEE, where an exceedance occurs and is rectified within 24 hours, the exceedance will have an immaterial effect on the calculations for the whole reporting period. Therefore, the Methodology's approach would appear to be reasonable.

[7] EPA Victoria, Best Practice Environmental Management Guide, "Siting, design, operation and rehabilitation of landfills" (2015), retrieved on 1 August 2017 from www.epa.vic.gov.au/~/media/Publications/788%203.pdf

Table 3: Victoria Best Practice Environmental Management - Landfill gas action levels (partial)

Location	Parameter(s)	Action level / unit
Landfill surface final cap	Methane concentration in air*	100 ppm
Within 50mm of penetrations through the final cap	Methane concentration in air**	100 ppm
Landfill surface intermediate cover areas***	Methane concentration in air*	200 ppm****

Notes:

* Point of measurement is 50mm above the landfill surface.

** Point of measurement is 50mm from the point of discharge.

*** Intermediate cover areas are those that do not have an engineered landfill cap and are not scheduled to receive waste during the next three months.

**** This value is inconsistent with the Measurement Determination, which indicates a value of 100 ppm. The value may have been 100ppm before revision.

The landfill gas action levels in the Victorian (and the ACT) guidelines are relatively low – other jurisdictions have limits of 500 ppm or no limit at all. As such, applying these action levels to the Methodology as methane concentration limits has resulted in few new ERF projects in Victoria.

2.2.4.3.1 Illustrative example

The effect is illustrated through a comparative theoretical analysis (refer to Appendix I) of the regulatory proportion in each jurisdiction for a landfill that:

- opened in 2000.
- accepted 100,000 tonnes in each year comprising 40% MSW (class 1), 40% C&I and 20% C&D.
- is wholly covered with final cover.

The NGER solid waste calculator (2016-17 version) was used to derive emissions (if no gas capture):

- QLD, NT (fast degradation rates): 91,887 tCO_2-e
- NSW (intermediate degradation rate): 85,831 tCO_2-e
- ACT, SA, TAS, VIC, WA (slow degradation rate): 60,721 tCO_2-e

Schedule 1 4(2) of the Methodology sets out the allowable flux rate for final cover in each state and territory (corresponding to methane concentration limits) of:

- ACT, VIC: 0.3×10^{-6} $tCH_4/m^2/hr$
- NSW, QLD, TAS, WA: 2.5×10^{-6} $tCH_4/m^2/hr$
- NT, SA N/A

Three scenarios have been considered in which the site area is 40, 20 or 10 hectares. Using equation 22 of the Methodology, the permitted annual methane flux for each scenario and each jurisdiction has been calculated as shown in Table 4.

Table 4: Permitted annual methane flux (t CO_2-e) for each scenario and jurisdiction

State \ Scenario	40 ha site	20 ha site	10 ha site
NSW, QLD, TAS, WA	243,333	121,667	60,833
ACT, VIC	29,200	14,600	7,300
NT, SA	no limit	no limit	no limit

Comparing these values with the estimated emissions without gas capture given above, the regulatory proportion in each State and Territory was calculated, as shown in Table 5.

Table 5: Regulatory proportion for each scenario and jurisdiction

State \ Scenario	40 ha site	20 ha site	10 ha site
ACT	52%	76%	88%
NSW	-	-	29%
NT	-	-	-
QLD	-	-	34%
SA	-	-	-
TAS	-	-	-
VIC	52%	76%	88%
WA	-	-	-

Equation 13 in the Methodology outlines that the applicable baseline is the maximum of the regulatory proportion and the default value. Assuming the default value of 30% applies in all States and Territories, then the applicable baselines are as shown in Table 6.

Table 6: Applicable baseline for each scenario and jurisdiction

State \ Scenario	40 ha site	20 ha site	10 ha site
ACT	52%	76%	88%
NSW	30%	30%	30%
NT	30%	30%	30%
QLD	30%	30%	34%
SA	30%	30%	30%
TAS	30%	30%	30%
VIC	52%	76%	88%
WA	30%	30%	30%

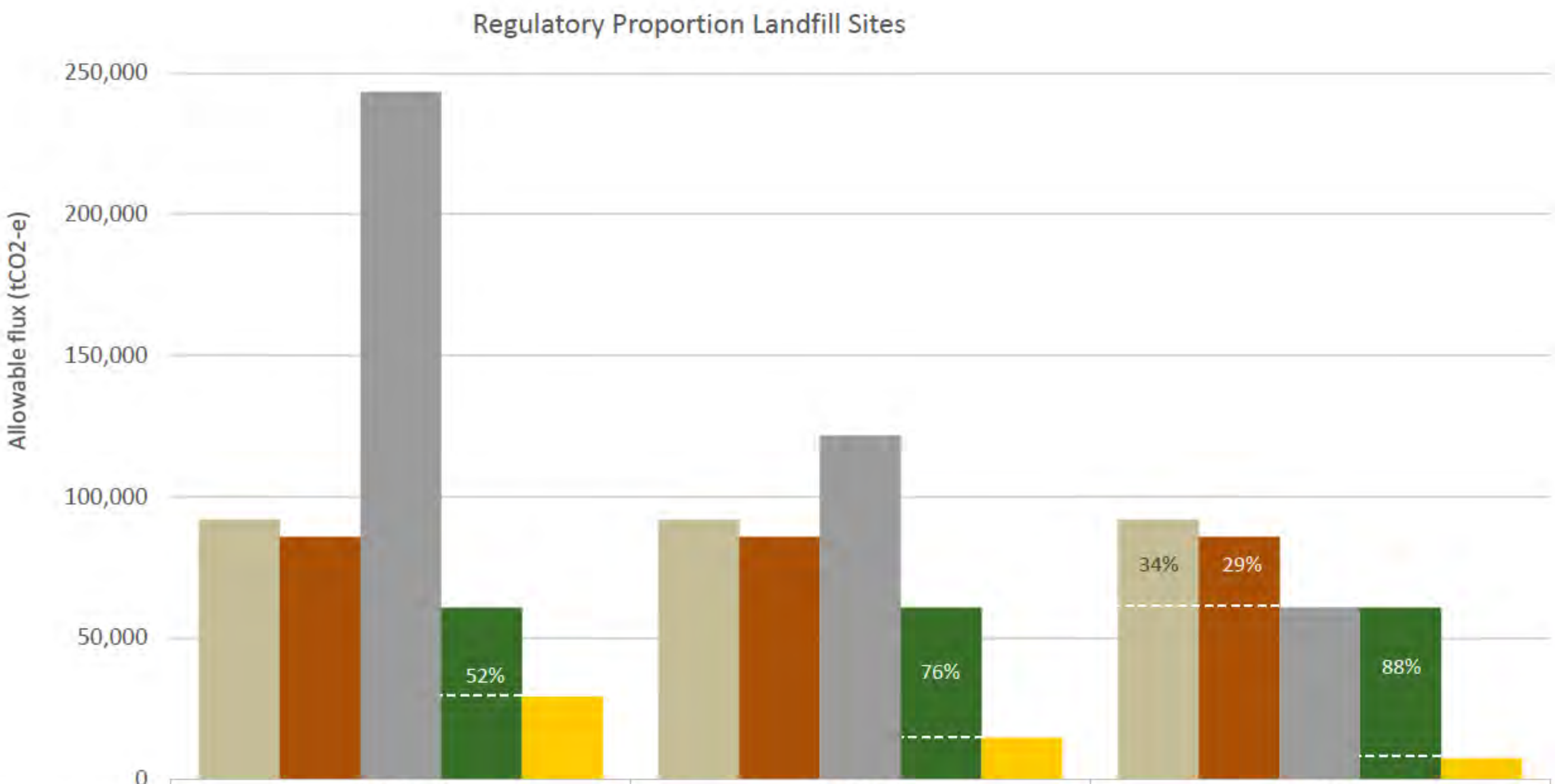
It is noted that the baselines are higher in Victoria (and the ACT) than any other state, which disincentivises ERF landfill gas projects. It is noted that the ACT has identical baselines to Victoria but has only one operating landfill which already captures high levels of landfill gas. The ACT is therefore unaffected by its high baseline.

To illustrate the above-mentioned scenarios, Figure 2 is provided. The estimated annual emissions are provided and the Allowable Flux for QLD, NSW and VIC. There the Allowable Flux is less than the estimated annual emissions, the difference between them is highlighted (as a percentage). This is, for scenario A,

- the allowable emissions for QLD and NSW are 243 ktCO_2-e and the annual estimated emissions are 92 ktCO_2-e for QLD and 86 ktCO_2-e for NSW. Consequently, there is no Regulatory Proportion for these sites; and
- the allowable emissions for VIC are 29 ktCO_2-e and the annual estimated emissions are 61 ktCO_2-e. The difference (for what a landfill site could claim ACCUs under the ERF) are 31.5 ktCO_2-e (which accounts for 52%). This represents the Regulatory Proportion, as indicated in Table 6.

Conclusion 3 Tighter (i.e. lower) landfill gas action levels in Victoria (and the ACT) create a higher Regulatory Proportion, modelled as 52%-88% depending on the landfill size. As such, in these cases, the Regulatory Proportion is higher than the default baseline of 30%. Consequently, the Regulatory proportion needs to be selected as the site's baseline.

Conclusion 4 The current Methodology approach to calculating abatement seems appropriate. It is noted that the default baseline of 30% was negotiated between the government and the industry in 2011. There has not been a subsequent operational data and re-calculation will require a more thorough investigation. It is expected that, the geographical location (given the organic decomposition rates, and hence the landfill gas generation rates) to be considered, amongst others.



	A (40 ha)	B (20 ha)	C (10 ha)
QLD Emissions	91,887	91,887	91,887
NSW Emissions	85,831	85,831	85,831
Allowable Flux (QLD & NSW)	243,333	121,667	60,833
VIC Emissions	60,721	60,721	60,721
Allowable Flux (VIC)	29,200	14,600	7,300

Figure 2: QLD, NSW & VIC landfill sites – allowable emissions (baseline representation)

2.3 Assessment of other government programs and financial incentives on the decision to undertake landfill gas capture and combustion at a landfill site.

Summary:

- *Most government programs address waste diversion, not landfill gas capture.*
- *Other financial incentives associated with landfill gas capture and combustion are:*
  - *the sale of electricity generated; and*
  - *the creation and sale of Large Scale Generation Certificates.*

There are multiple State-based and local government incentives for diverting organic waste from landfills, but apart from the ERF there are negligible, or no, similar incentives to capture landfill gas. Pre-existing programs such as 'Greenhouse Friendly', the NSW GGAS and the Carbon Farming Initiative (CFI) have been folded into the ERF. The main complementary government program that landfill gas projects can access is the revenue from the generation and sale of electricity and associated Large Scale Generation Certificates (LGCs).

Landfill gas projects can be divided into two types:

- *Flaring projects*, where landfill gas is collected to combust it. This type of project typically occurs at smaller landfills, sites which are far from the electricity grid, younger sites that are not yet generating much gas, or older sites that are largely depleted of gas (refer to section 2.3.1).
- *Energy generation projects*, typically (in Australia) involving feeding the collected landfill gas into a gas reciprocating engine generator that is connected to the electricity grid. This typically occurs at large sites over the bulk of their landfill gas generating life (refer to section 2.3.2).

2.3.1 Flaring projects

Capital costs for a flaring project would typically be in the hundreds of thousands of dollars (refer to section 6.3 for additional information.) For these projects, there is no other source of revenue to collect gas other than the ERF. If an ERF flaring project was no longer eligible and the landfill was not obliged to capture gas by the State or Territory regulator or local community expectations as explained in section 2.2.4.2, it could be expected the gas capture and flare system to degrade and cease operation. This is because:

- Landfills contain biologically active putrescible waste and landfill gas is wet, corrosive, and contains traces of remnant putrescible waste. Because of this, the equipment degrades and requires ongoing maintenance to maintain its adequate operation; and
- Landfills are typically constructed in discrete 'cells' that are progressively established across the site. Landfill gas production moves with the landfilling, so new bores need to be regularly established. Without an incentive to establish new bores, the flaring system would be likely to deplete the gas from the current operational cells and then close.

Some sites with flares may continue flaring due to regulator pressure or community expectations. These sites could be expected to do the minimum to achieve these ends. This is likely to represent a reduction in gas capture levels under the ERF, which incentivises capture and destruction of each tonne of methane.

2.3.2 Energy generation projects

The costs for energy generation projects greatly exceed those for flaring. Capital costs for the reciprocating engines are typically AUD$1.8m per megawatt electrical (MWe) (refer to section 6.3). As the power generation engines are modular (i.e. additional power generation engines are installed as the gas build-up allows for their operation), the costs are predominantly linearly scalable. It is noted that most of the projects are implemented in a staged manner. In consideration of additional required electrical infrastructure (i.e. connection systems), these costs could escalate to ~AUD$2.5m per MWe.

The sale of electricity and LGCs provides an incentive for electricity generation which will vary by site and on the stage of the landfill (or project) lifecycle. Specific project data could not be obtained as this information is not public and the project owners were not willing to share the details. Nevertheless, to illustrate how the value of ACCUs relate to the total project income, a high-level assessment was performed. These figures consider the most recent estimate (i.e. 2017) and a 2013 estimate. The 2013 estimate was selected for illustrative purposes and it is noted that this period was when compliance ACCUs had a fixed price.

2.3.2.1 'Bundled' Power Purchase Agreements consideration

To assess how the incentives correlate given the volatility in price, the electricity and LGCs values were 'bundled'. These incentives covered both electricity and LGCs, which are based on long term power purchase agreements (PPAs). It is noted that the PPAs value has been declining. Figure 3 shows that these prices have approximately halved since projects commenced in 2012.

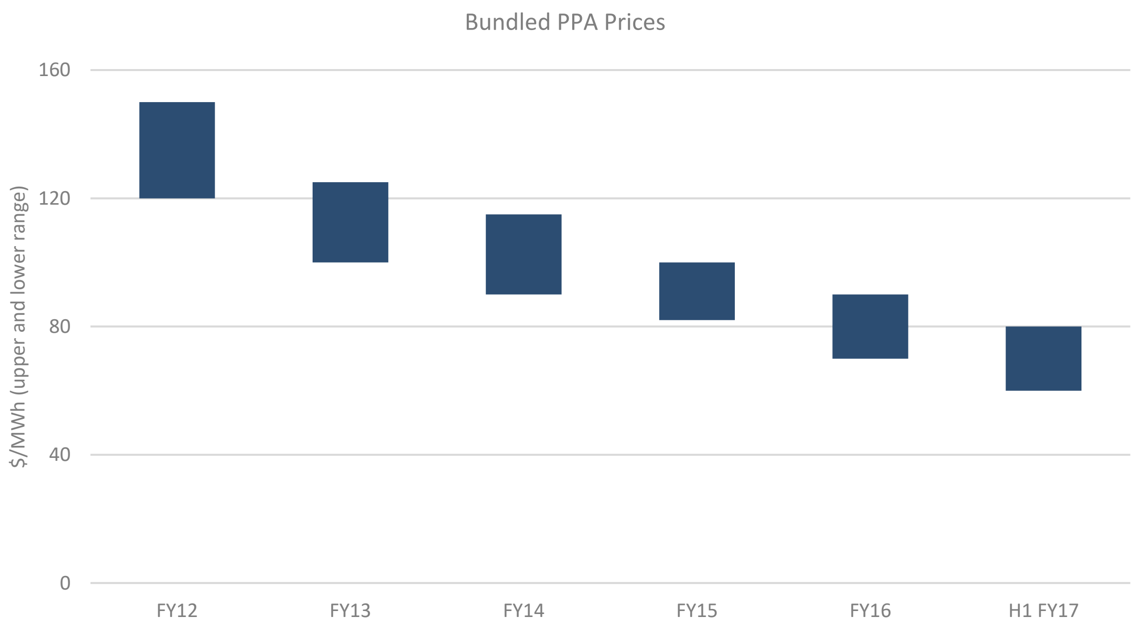


Figure 3: Annual trend, PPA prices[8]

[8] Vorrath, S. and Parkinson G. (2017), "Origin signs up for 200MW solar plant in S.A, as PPA prices tumble", retrieved from http://reneweconomy.com.au/origin-signs-up-for-200mw-solar-plant-in-s-a-as-ppa-prices-tumble-86240/

2.3.2.1.1 Upper and lower price scenarios

To assess how the incentives vary, given the upper and lower values provided in Figure 3, two scenarios were considered. The scenarios consider the upper and lower bundled LGC costs, whilst the value of ACCUs was not varied. The analysis considers a site with a 30% baseline, 33% efficient engines and the following constant estimated financial incentives:

- The ACCUs price (noting that each ERF contract has a unique and confidential price) for both high and low scenarios considered:
  - For the most recent estimate (2017): $11 per ACCU; and
  - For 2013: $23 per ACCU. It is noted that during this period, compliance ACCUs had a fixed price at first of $23.00, and then $24.15.
- The following 'bundled' PPA values were considered:
  - For the most recent estimate (2017):
    - The low scenario considered $60 per MWh (recent large projects sold at ~ $55[9] to $65[10] per MWh); and
    - The upper scenario considered $80 per MWh.
  - For the 2013 estimate:
    - For the low scenario $100 per MWh was considered; and
    - The upper scenario considered $120 per MWh.

The results are provided in Table 7 and graphically presented in Figure 4 and Figure 5.

Table 7: Estimated Financial Incentives (2017 and 2013)

Estimated Financial Incentives	2013 estimate		Latest (2017) estimate	
	Low Scenario	High Scenario	Low Scenario	High Scenario
ACCUs	44%	39%	39%	32%
Electricity generated and LGCs 'bundled'	56%	61%	61%	68%

[9] Origin PPA $50-$60 http://reneweconomy.com.au/origin-stuns-industry-with-record-low-price-for-530mw-wind-farm-70946/

[10] AGL Silverton windfarm at $65 http://reneweconomy.com.au/agls-new-200mw-silverton-wind-farm-to-cost-just-65mwh-94146/

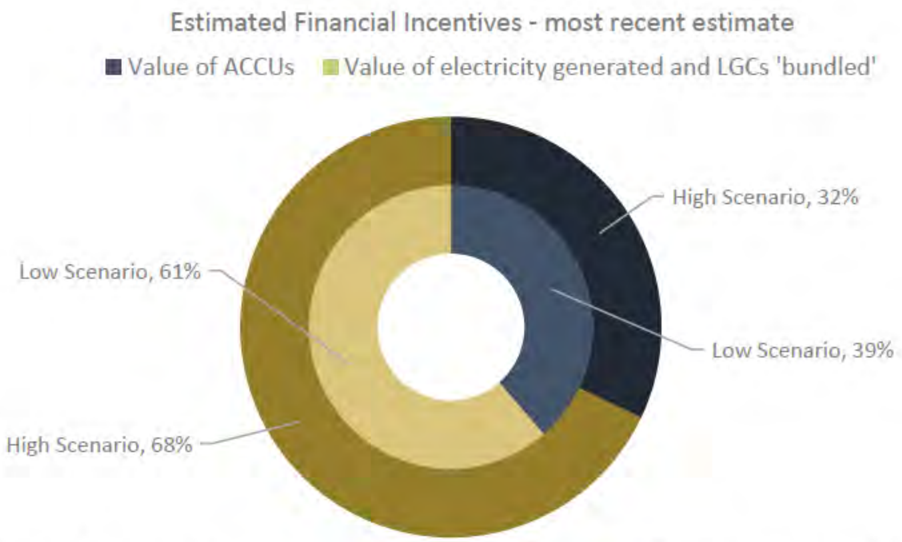


Figure 4: Estimated Financial Incentives – Energy Generating Project – most recent estimate

As highlighted in Figure 4 using this data, the sale of ACCUs at present (2017) represents approximately 39% in the low scenario and 32% in the high scenario of the financial incentive of the project. A summary of the calculations is provided in Appendix F.

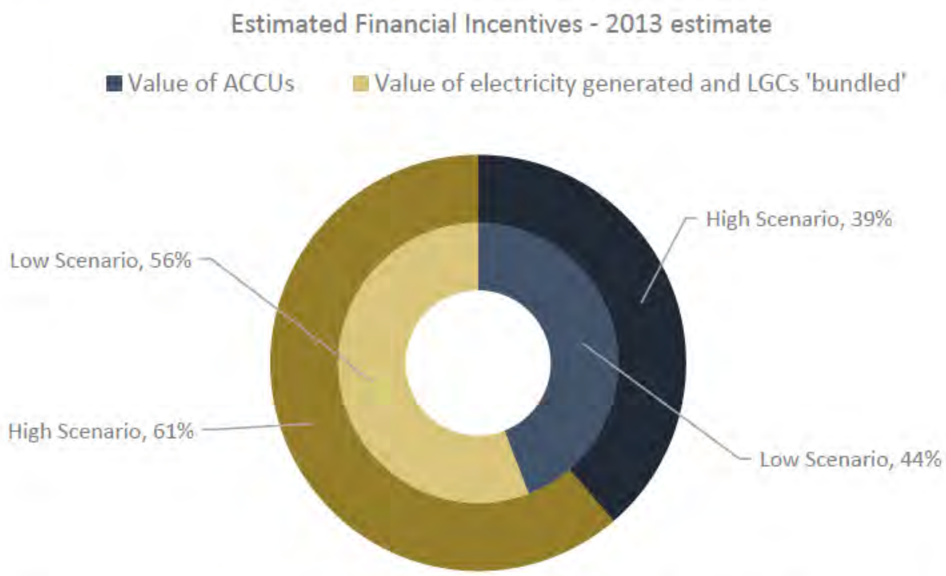


Figure 5: Estimated Financial Incentives – Energy Generating Project – estimate for 2013

Conversely, Figure 5 highlights that the sale of ACCUs estimated using 2013 values, the ACCUs would represent approximately 44% in the low scenario and 39% in the high scenario.

2.3.2.2 Sensitivity of the value of ACCUs

To consider the variance and sensitivity of the value of ACCUs, the following assessment was undertaken. The most recent estimates (2017) – low scenario details were considered. The value of the 'bundle' PPA was fixed at $60 per MWh. The value of ACCUs was varied from $15 to $8 per ACCU. The results are shown in Figure 6.

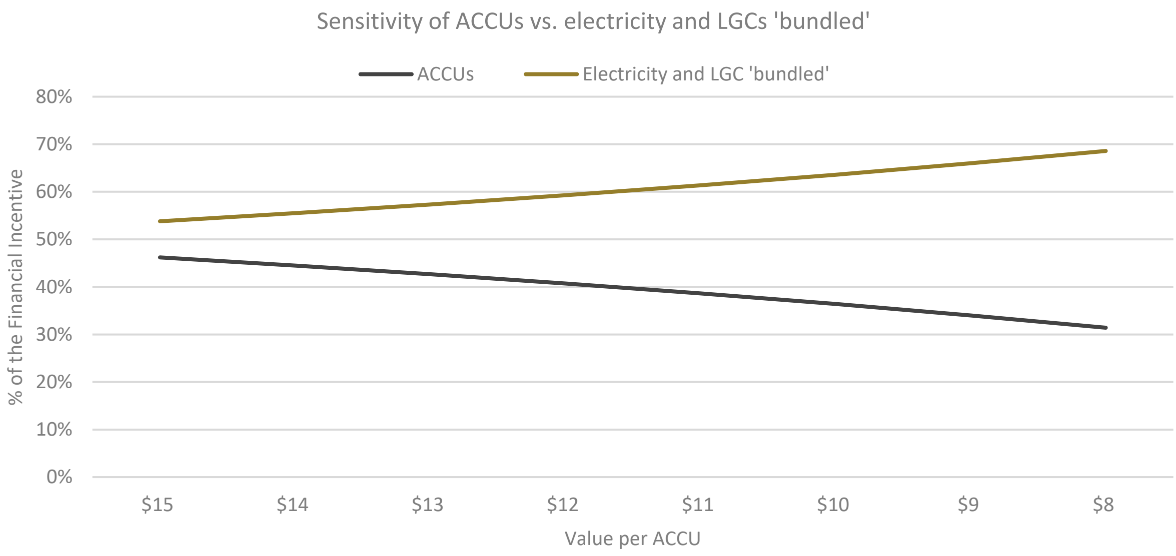


Figure 6: ACCUs sensitivity vs 'bundled' PPA

As shown in Figure 6, a price of $15 per ACCU would represent approximately 46% of the financial incentives of a project. Similarly, a price of $8 per ACCU would represent approximately 30%. This correspond to a 2 or 3% variance in the financial incentive for every dollar varied in the ACCU price. More information on the financial performance is provided in section 6.3.

2.3.2.3 Relation between the value of ACCUs and the abatement

This section explores the potential impact of ACCU income on the volume of landfill gas destroyed. Figure 7 shows the annual trend since 1990 for both flare and electricity projects combined. The following periods are highlighted:

- From 1990 to 1995 there is a small increase (i.e. from an almost zero baseline in the amount of landfill gas destruction to nearly 1,000 ktCO_2-e).
- From 1995 to 1998 there is a steep increase of nearly 2,000 ktCO_2-e in abatement. This increase is driven presumably mainly by the ability to sell electricity. Also, other factors may be the odour regulations, guidelines and community concerns and the introduction of 'green' tariffs in some States and the Renewable Energy Target (RET) in 1997.
- From 1998 to 2002 the growth appears to level off, until 2003 when the GGAS scheme was introduced.
- In 2003, a significant increase in capture rates occurred, until another flat period from 2005 when GGAS prices and regulatory certainty 'stalled' during CPRS (carbon tax) discussions, until the introduction of the CFI and carbon tax in 2011.
- The growth stalled with the loss of the carbon tax value in 2014.
- The commencement of ERF auctions in 2015 continued to marginally increase recovered GHG emissions.

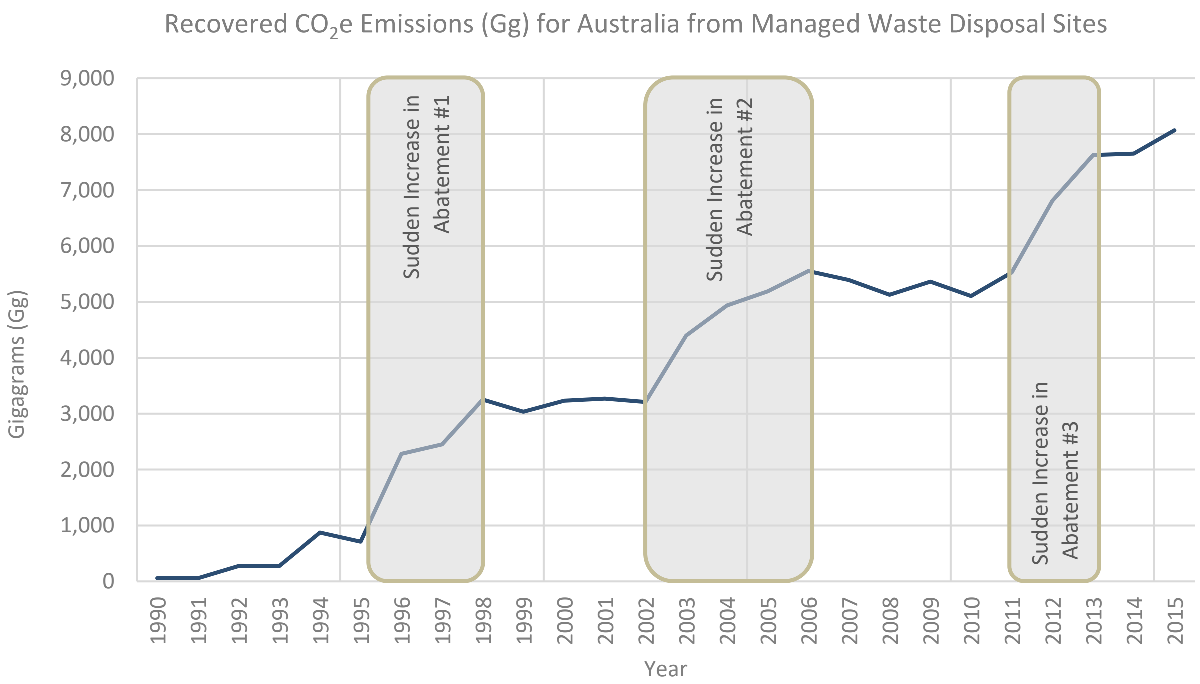


Figure 7: Annual trend, emissions reductions at landfill sites[11]

It is noted that two types of drivers have been identified that may have influenced the GHG emissions abatement, these are:

- Sudden changes: three sudden changes can be perceived as indicated in Figure 7. As highlighted above, these changes coincide with:
  - Financial drivers, such as:
    - Ability to sell electricity in 1995;
    - GGAS introduction in 2003; and
    - Carbon tax introduction in 2011.
- Gradual changes: other drivers that may influence the abatement of GHG emissions, albeit in a more gradual manner (i.e. cannot be pinpointed in Figure 7) are:
  - Regulations; whilst no specific requirements of the abatement required, the introduction of State and Territory regulation affects the amount abated;
  - Community complaints / concerns over odour;
  - Other incentives:
    - Modular power generation technology (i.e. technology improvement / cost decrease of power generation and flaring equipment);
    - Landfill management intent (including reputational benefits, environmental values, quality objectives and susceptibility to public perception);
    - Health and safety issues or concerns (including impacts to the environment, human health and amenity); and
    - Risk Management (e.g. mitigate asphyxiation, explosion and migration potential).

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[11] Department of the Environment and Energy, National Greenhouse Gas Inventory, "Recovered CO_2e Emissions (Gg) for Australia from Managed Waste Disposal Sites". Retrieved from: http://ageis.climatechange.gov.au/Chart_KP.aspx?OD_ID=70067876761&TypeID=2

In summary, it appears that landfill gas destruction volumes have increased when incentives for methane destruction are present (particularly when there are financial incentives present), and have stalled (and even decreased as highlighted in the period 2006 to 2010) when they are absent.

As noted in section 6.3.2.1, Table 27 shows that the availability of financial incentives for GHG emissions abatement results in revenue (for both; flare and electricity generation projects) in consideration of the life of asset (considered to be 7 years in accordance with the ERF contracting period). Furthermore, the absence of these incentives results in a cost to the site despite the revenue from the electricity generation and the renewable energy certificates.

<u>Conclusion 5</u> The establishment of most landfill gas collection systems correlates with the introduction of financial incentives from the creation of GHG emissions abatement and/or the generation of electricity. Gas collection in 2015 was 2.5 times (8,070 ktCO_2-e in 2015 versus 3,210 ktCO_2-e in 2002) that before incentives (beyond the value of electricity) were introduced in 2003. These incentives appear to drive and maintain investment in landfill gas collection. Without them, investment is likely to commence later in the lifecycle of cells and be lower, leading to collection rates declining in existing projects. This conclusion is more certain in relation to landfill gas flaring but also applies to energy generation projects.

2.4 Whether projects/activities covered by the method are required to be carried out by, or under, a law of the Commonwealth a State or Territory.

<u>Summary:</u>

Regulations of landfills follow a tiered approach:

i. State legislation and regulation,
ii. Landfill guidelines, and
iii. Site-specific licences.

The focus, regulation and enforceability of requirements vary across Australia. There is no explicit indication in the regulations of how the size of a landfill and its proximity to population centres effects gas capture requirements.

<u>Note:</u>
Based on the assessment of the requirements of this section, parts (i) and (ii) (as stated below) are interrelated and reference each other constantly, consequently, the assessment has focused on both parts together:

i. When addressing this part of the criterion the Service Provider will assemble and provide information on regulatory requirements (including guidelines, regulations or other policy) for landfill gas capture and combustion for each State and Territory and evaluate how these translate into actual gas capture requirements on-site.
ii. The Service Provider will undertake an analysis of licence requirements for waste disposal activities. The analysis will examine the extent to which landfills are required to capture landfill gas and how this differs between States or Territories and landfills of different sizes and proximity to population centres.

2.4.1 Legal structure under which most landfills operate

Landfills typically operate under a three-tier legal structure. This structure provides the framework of requirements and includes:

- Overarching legislation and regulatory requirements (section 2.4.1.1),
- Landfill guidelines (section 2.4.1.2), and
- Site specific landfill licences (section 2.4.1.3).

As noted above, in the Methodology, the default baseline value is 0% if the landfill has not been subject to legislation or regulatory guidelines for gas collection, and 30% otherwise. It is understood that there are few sites where the 0% baseline has been determined to apply for new projects. Consequently, the 30% default baseline generally applies.

2.4.1.1 Overarching Legislation and Regulation

There is no overarching federal legislation that governs the operations of landfills. Each State and Territory has its own set of legislation and regulations that set binding requirements on landfills (refer to Appendix A for an exhaustive list).

These binding requirements are general in nature, and mostly relate to the State-based Environmental Protection Acts. Emphasis is made in the regulations requiring the general provision that "environmental harm shall not occur" (i.e., a person shall not pollute or reduce local environmental amenity).

In Victoria, as an example, the Siting, Design, Operation and Rehabilitation of Landfills document[12], which is subservient to the Environment Protection Act, states that the "authority may require a landfill operator to install a landfill gas collection system". As with other States, this provision relates to a risk management activity (e.g. odour, toxicity and explosion risk). This provision has driven the installation of capture and combustion devices (i.e. flaring and power generation systems) as there are financial incentives available (e.g. sale of ACCUs, electricity generation and/or LGCs). It is noted that other activities could be implemented that meet the provision without having nearly as much impact on the GHG abatement, such as:

- Better capping material that reduce the rate of direct emissions of landfill gas;
- Improved lining to prevent uncontrolled movement of landfill gas through the base and sides of the landfill site;
- Improved leachate management and control of rainwater ingress; and
- Gas pressure management (i.e. reduction of built-up gas pressure by increasing gas extraction).

<u>Conclusion 6</u> Legislative or regulatory requirements specifically requiring landfill gas capture at landfills relate primarily to risk management activities (e.g. odour, toxicity and explosion risk), rather than GHG emissions abatement activities. Management tools other than collection/flaring, such as better capping materials, could achieve legislative compliance but at a lesser rate of GHG emissions abatement.

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[12] EPA Victoria (2015), Siting, design, operation and rehabilitation of landfills. Retrieved on 1 August 2017 from http://www.epa.vic.gov.au/~/media/Publications/788%203.pdf.

2.4.1.2 General Policy and Guidelines

Each State and Territory[13] has developed its own specific set of guidelines (refer to Appendix B for details). The guidelines are designed to:

- Provide guidance and set aspirational targets of how an optimal landfill should operate; and
- Assist landfills meet specific State or Territory environmental objectives.

Guidance and licence requirements on landfill gas management are considered in two broad categories:

A. *General requirements* to minimise or control gas emissions and odour; and
B. *Specific requirements* to prevent gas concentrations above the landfill surface exceed specified levels.

Some guidelines such as those in New South Wales[14] (page 31) and South Australia[15] (section 8.3) do specifically mention GHG emissions minimisation. However, the documents focus on other environmental and safety issues such as odour and methane concentrations at the boundary of the site.

New South Wales and Victoria's guidelines refer to the UK's Guidance on the Management of Landfill Gas (LFTGN 03). The Guidance requires a risk assessment focusing on the "potential impacts on local environment, health and amenity" (p. 17). As such, the potential impacts relate to nearby receptors and potential gas migration pathways. As these requirements are site-specific, it is not possible to provide a robust general formula that translates these requirements into a universal numeric gas capture rate. Nonetheless, some gas collection advice is provided for example:

- that an active gas extraction system be designed to achieve the maximum practicable collection efficiency (85% suggested); and
- that a methane flow rate exceeding 50-100 cubic meters is an indication that a gas extraction system is required.

There are specific requirements that relate to the size of the landfill (e.g. Tasmania's requirement applies for sites that exceed 20,000 tonnes per annum in any three consecutive years – refer to 2.4.1.3.1.7). Furthermore, it is noted that larger landfill sites are normally better placed to install electricity generation engines due to economic practicability and landfill gas availability.

Conversely, specific requirements related to proximity to population were not found. Nevertheless, the landfill's proximity to population will have a higher risk factor (e.g. health and safety, odour complaints, etc.) and may result in specific site restrictions.

Table 8 provides a summary of the specific and general requirements, including the stipulated threshold concentration levels. If the threshold concentration levels are exceeded, certain actions are triggered. It is noted that should a landfill fail to meet its surface emissions test, it is generally cause

[13] Apart from the ACT which has adopted Victoria's Best Practice Guidelines.
[14] NSW EPA, Environmental Guidelines: Solid waste guidelines, second edition, 2016
[15] SA EPA Guidelines, Environmental management of landfill activities (municipal solid waste and commercial and industrial general waste), January 2007

for repeated, more frequent testing and not necessarily an automatic matter for penalty. Individual regulators will follow their own risk based education and enforcement procedures.

Appendix D summarises the exceedance responses across the States and Territories, also refer to Table 2 in section 2.2.4.1.1 for a record of compliance in Victoria.

Conclusion 7 Landfill gas capture is mentioned in State and Territory guidelines on appropriate landfill management. Nevertheless, these guidelines focus on potential environmental and health and safety risks such as; methane concentrations at the boundary of the site, odour and potential impact on receptors and potential gas migration pathways. Landfill gas combustion seems to be the most effective (and given the financial incentives), the most economical means to address these requirements. Nevertheless, landfill sites might implement other activities (refer to section 2.4.1.1) that will result in compliance with the guidelines without the abatement of GHG emissions.

Table 8: General and specific requirements for landfill gas management

Item	Parameter	States / Territories with specific requirements			States / Territories with guidance thresholds (enforcement by some States under site specific licence conditions)				
		NSW	VIC	QLD	SA	TAS	NT	WA[16]	ACT
Landfill surface final cover[17]	Methane	500 ppm	100 ppm	500 ppm	No limit	500 ppm	No limit	Under review	-
Within 50mm of penetrations through the final cap[5]	Methane	NA	100 ppm	NA	NA	NA	-	Under review	-
Landfill surface intermediate cover areas[18]	Methane	500 ppm	200 ppm[19]	500 ppm	NA	500 ppm	-	-	-
Within immediate vicinity of penetrations through intermediate cover[5]	Methane	NA	1000 ppm	NA	No limit	NA	No limit	Under review	-
Subsurface geology at the landfill boundary	Methane and carbon dioxide	1% v/v CH_4 and 1.5% v/v CO_2 above background	1% v/v CH_4 and 1.5% v/v CO_2 above background	25% LEL	1% v/v CH_4 and 1.5% v/v CO_2 above background	1.25% v/v CH_4	1% v/v CH_4 and 1.5% v/v CO_2 above background (where buildings are within 250m of site)	Under review	-
Subsurface services on and adjacent to the site	Methane and carbon dioxide	1% v/v CH_4 (within all buildings and other enclosed structures with 250m of deposited waste)	10,000 ppm	25% LEL	1% v/v CH_4 and 1.5% v/v CO_2 above background	1.25% v/v CH_4	-	Under review	-

[16] Current requirements reference the UK's Construction Industry Research and Information Association (CIRIA) C665. However, WA is currently reforming its regulatory framework.

[17] Point of measurement is 5cm from surface or point of discharge.

[18] Intermediate cover areas are those that have not reached final profile and are not scheduled to receive waste during the next three months.

[19] This value is inconsistent with the Measurement Determination, which indicates a value of 100 ppm. The value may have been 100ppm before revision.

Item	Parameter	States / Territories with specific requirements			States / Territories with guidance thresholds (enforcement by some States under site specific licence conditions)				
		NSW	VIC	QLD	SA	TAS	NT	WA[16]	ACT
Buildings/structures on and adjacent to the site	Methane and carbon dioxide	1% v/v CH_4 (within all buildings and other enclosed structures with 250m of deposited waste)	5,000 ppm	25% LEL	1% v/v CH_4 and 1.5% v/v CO_2 above background	-	1% v/v CH_4 and 1.5% v/v CO_2 above background (where buildings are within 250m of site)	Under review	-
Landfill gas flares	Volatile organic compounds (excluding methane)	Gas residence time >0.6 s, Combustion temp >760°C, 98% destruction efficiency Emissions from landfill gas combustion must not exceed concentration limits in the POEO (Clean Air) Regulation 2010	98% destruction efficiency	-	98% destruction efficiency Control of combustion emissions to comply with the Environment Protection (Air Quality) Policy 1994 (updated 2016)	-	-	-	-
Bio filters	Methane flux	-	1.0g/m²/hr	-	-	-	-	-	-
Regulatory / Guidance document		NSW EPA Guidelines / Licences	VIC BPEM Guidelines / Licences	ERA 60	SA EPA Guidelines (enforcement is site specific - development applications and / or licences)	TAS EPA Guidelines	NT EPA Guidelines		

2.4.1.3 Specific Landfill Licence Requirements

Licences set out site-specific requirements, breaches of which can typically attract immediate fines or prosecutions. Historically, landfill licences were often tailored to a site but recently, New South Wales and Victoria have moved towards more generic licencing that refers to landfill guidelines, adopting a risk-based approach to licensing requirements (refer to Appendix C for general licence requirements).

Requirements related to the capture of landfill gas are present in some licences, however specific requirements (e.g., the percentage or volume of landfill gas capture required) are not mandated. New South Wales and Victoria's licences reference best practice guidelines, which also do not specifically require some absolute or proportional quantity of gas capture.

2.4.1.3.1 Licence review methodology

An online review of publicly available landfill licences was undertaken as part of the engagement. The number of licences retrieved and reviewed are summarised in Table 9. For each licence consulted, the requirements related to the landfill gas were summarised in a spreadsheet. This spreadsheet has been provided as Annex A. A thorough review of these requirements was undertaken and a summary of the requirements was made. The summary is provided in Appendix C. Key notes for each State are provided in the below sections and a sample of the licences consulted is provided in Annex B.

Table 9: Landfill gas licence requirements reviewed by State

State	Section	Current (estimated) no. sites[20]			No. of licences reviewed		
		Landfill	Multi-purpose	Total	Landfill	Multi-purpose	Total
NSW	2.4.1.3.1.1	263	101	364	35	19	54
VIC	2.4.1.3.1.2	156	45	201	7	0	7
NT	2.4.1.3.1.3	140	4	144	1	0	1
WA	2.4.1.3.1.4	254	29	283	2	3	5
SA	2.4.1.3.1.5	109	24	133	4	1	5
QLD	2.4.1.3.1.6	226	35	261	30	0	30
TAS	2.4.1.3.1.7	17	2	19	NA	NA	
ACT	2.4.1.3.1.8	1	1	2	1	0	1
Total		1,166	241	1,407	80	23	103

Note: NA (Not available).

[20] It is noted that the data may contain duplicated records for a single site. The data may have also considered non-operational sites.

2.4.1.3.1.1 New South Wales

New South Wales licences were made available by the NSW Environmental Protection Agency (EPA) POEO[21] Public Register[22]. Licences were searched by the fee-based activity for 'waste disposal by application to land', returning all available licences in the State for this activity. It is noted that 157 records were found. The licences do not provide details of the landfill size. A representative example of actual licence conditions is provided below (*emphasis added*):

> *Landfill Gas Oxidation*
>
> O5.14 Except in emergency conditions or short periods of shutdowns the licensee must ***ensure that landfill gas generated*** by the disposal of waste and collected at the premises is ***treated by oxidation to carbon dioxide***.

2.4.1.3.1.2 Victoria

Victoria licences were made available by the VIC EPA Interaction Portal[23]. Reviewed licences indicated that requirements are general and refer to the Best Practice Environmental Management (BPEM) Guidelines. The licences do not provide details of the landfill size. A representative example of actual licence conditions is provided below (*emphasis added*):

> *Landfill Conditions*
>
> LI_L5 You must ***take all practicable measures to prevent emissions of landfill gas from exceeding the action levels*** specified in Table 6.4 of Best Practice Environmental Management, Siting, Design, Operation and Rehabilitation of Landfills (EPA Publication 788.3, released August 2015).

2.4.1.3.1.3 Northern Territory

The only Northern Territory licence that could be retrieved was made available by the NT EPA website[24]. In the licence, the landfill gas requirements are general in nature. There are eight (8) landfills listed in the page. It is understood the licence retrieved is the biggest landfill in the Territory. The licences do not provide details of the landfill size. A representative example of actual licence conditions is provided below (*emphasis added*):

> *Licence Conditions*
>
> Emissions to air
>
> 42 The licensee must ensure that pollution control equipment, ***including landfill gas collection equipment, is installed, operated and maintained*** to minimise contaminants or waste in emissions to air.

---

[21] Protection of the Environment Operations

[22] List of Licenses available at http://www.epa.nsw.gov.au/prpoeo/licences.htm

[23] EPA Interaction Portal, last accessed on 7 August 2017, from https://portal.epa.vic.gov.au/irj/portal/anonymous?NavigationTarget=ROLES://portal_content/epa_content/epa_roles/epa.vic.gov.au.anonrole/epa.vic.gov.au.searchanon&trans_type=Z001

[24] Information retrieved on 14 July 2017 from https://ntepa.nt.gov.au/waste-pollution/approvals-licences/environment-protection-licences

2.4.1.3.1.4 Western Australia

Western Australian licences were made available by WA Department of Water and Environmental Regulation website[25]. The reviewed licences indicated that the requirements are site specific. The publicly available licences are scanned copies, often illegible, incorrectly formatted, cropped and often missing pages. A representative example of actual licence conditions is provided below (*emphasis added*):

> Landfill Conditions
>
> Licence Condition 1.2.9 has been added to the Licence to ensure that collection and combustion of landfill gas occurs within reasonable timeframes to mitigate asphyxiation, explosion and migration potential.
>
> 1.2.9 The Licensee must connect infrastructure detailed in Item 3 ('Aspiration wells'), Column 1 of Table 1.2.1 to active landfill gas management systems *capable of capture and combustion of landfill gas* no later than 90 days following the completion of the construction of those wells.

2.4.1.3.1.5 South Australia

South Australian licences were made available by the SA EPA search authorisations[26]. Licences were searched by the activity for 'waste or recycling depots (solid waste for on-site disposal)', returning all available licences in the State for this activity. The licences do not provide details of the landfill size. A representative example of actual licence conditions is provided below (*emphasis added*):

> *Conditions of Licence*
>
> 3.13 Revised Landfill Environment Management Plan (U - 393)
>
> The Licensee must:
>
> 3.13.2 Ensure the Northern Adelaide Waste Management Authority Landfill Environmental Management Plan includes but not be limited to updating the management of groundwater, leachate, surface water, landfill gas, landfill capping and closure and post closure monitoring.

2.4.1.3.1.6 Queensland

Queensland licences are divided mainly in two, as follows:

- ERA 60 - Waste disposal 1: Operating a facility for disposing of, in a year, the following quantity of waste mentioned in subsection (1)(a)
  a) less than 50,000t
  b) 50,000t to 100,000t
  c) more than 100,000t but not more than 200,000t
  d) more than 200,000t
- ERA 60 - Waste disposal 2: Operating a facility for disposing of, in a year, the following quantity of waste mentioned in subsection (1)(b)
  a) 50t to 2,000t
  b) more than 2,000t but not more than 5,000t
  c) more than 5,000t but not more than 10,000t
  d) more than 10,000t but not more than 20,000t

---

[25] Information retrieved on 14 July 2017 from https://www.der.wa.gov.au/our-work/licences-and-works-approvals/current-licences

[26] Information retrieved on 14 July 2017 from http://www.epa.sa.gov.au/data_and_publications/environmental_authorisations_licences/search-authorisations#/search?location=area&type=A

e) more than 20,000t but not more than 50,000t
f) more than 50,000t but not more than 100,000t
g) more than 100,000t but not more than 200,000t
h) more than 200,000t

Depending on the annual tonnes a landfill is licenced for, the specific landfill gas requirements vary. Below, the smallest landfill site licence (i.e. ERA 60 Waste disposal 1(a) – less than 50,000t) and the biggest (i.e. ERA 60 Waste disposal 2(h) - more than 200,000t) are provided below. It is noted that (from the licences reviewed – refer to Table 9) most of the licences do not have a requirement to capture and combust any landfill gas. Nevertheless, for the bigger landfill sites (i.e. from ERA 60 2 (e) onwards), the requirements to manage landfill gas is present (although not for all the landfills that fall in that category). Some of the requirements are provided below (*emphasis added*) and more detailed information is provided in Appendix H.

Conditions of Licence (ERA 60 Waste disposal 1 (a)

No requirement

Conditions of Licence (ERA 60 Waste disposal 2 (h))

Management of Landfill Gas

(B3) A collection system for landfill gas *must be installed and maintained to efficiently minimise*:

i. any likelihood of any *subsurface migration of landfill gas from the landfill unit*; and
ii. any uncontrolled emission of landfill gas.

(B4) An interim perimeter active landfill gas collection system for all cells must be installed prior to installation of the final gas collection system. This system is to be installed forthwith after the landfill cell is sufficiently elevated to allow adequate drainage of gas lines.

(B5) *Landfill gas collected by the gas collection system must be incinerated* prior to release to the atmosphere or provided as an alternative fuel source or collected and stored in a proper and efficient manner for later use.

(B11) There must be no visible emissions from the landfill gas flare.

(B12) The release of landfill gas from the landfill must not exceed:

i. *25 percent of the lower explosive limit for methane* when measured in landfill facility structures (but excluding landfill facility structures used for landfill gas control and landfill gas recovery system components); and
ii. the lower explosive limit for methane at the landfill facility boundary.

2.4.1.3.1.7 Tasmania

Whilst no licences could be retrieved, interviews with the EPA regulator indicated the following requirements:

Landfill Requirements

OP8 – Landfill gas management

- If waste deposition on The Land, excluding cover material, exceeds 20,000 tonnes per annum in any three consecutive years, landfill gas management infrastructure must be installed progressively as final capping is installed; and
- Following installation of landfill gas management infrastructure *landfill gas must either be collected and reused, or flared*.

2.4.1.3.1.8 Australian Capital Territory

Licence (authorisation) No. 0375 for Remondis Australia Pty Ltd was consulted. The below are the gas management requirements:

Landfill Requirements

27 Gas Management

27.1 The Authorisation holder shall undertake a site-specific landfill gas risk assessment acceptable to the Authority within three (3) months of the approval of this Authorisation.

27.2 The Authorisation holder shall undertake monitoring of landfill gas in accordance with section 6.7.1 landfill gas and Table 6.4 of the 'Best practice environmental management, siting, design, operation and rehabilitation of landfills' (Victorian Environment Protection Authority publication 788) as updated from time to time and record the following information on a monthly basis:

- methane concentration;
- carbon dioxide concentration;
- landfill gas temperature; and
- atmospheric temperature and pressure.

27.3 The Authorisation holder shall provide the Authority with a written report once per calendar month from the grant date of this authorisation detailing the results obtained in undertaking the monitoring as detailed in condition 27.2.

Conclusion 8 Landfill licences vary across States and within States (e.g. depending on the landfill size) and are applicable to individual sites. Some landfill licences do require landfill gas capture and management. Despite the requirement being intended to mitigate potential risks, these requirements result in GHG emissions mitigation. It is noted that because these requirements don't specify the extent of (i.e. how much gas) landfill gas that must be managed (e.g. captured and combusted), these requirements account for the 30% qualitative baseline in the Methodology.

2.5 Whether the additionality requirements of the method present a barrier to projects that would provide genuine and additional abatement.

Summary:

There are barriers to projects that would provide genuine and additional abatement including:

- *the qualitative baseline, particularly in Victoria, and*
- *the non-carbon tax waste percentage calculations, particularly for small landfills.*

2.5.1 Qualitative baseline

As previously highlighted in section 2.2.4, the qualitative baseline is a key element of the Methodology. With this baseline being a flat 30%, it is possible that some projects face a barrier for receiving ACCUs for genuine additional abatement. The baseline tests were designed in 2011 using data available at the time.

2.5.1.1 Victorian quantitative test

As previously highlighted in section 2.2.4.3, Equation 13 and Equation 22 (quantitative) in the Methodology reference regulatory requirements for maximum methane concentration above the surface of the landfill. Applying these to Victorian sites, assuming a maximum 100 parts per million (ppm) of methane concentration above the surface of the landfill, results in a baseline greater than the default 30% (refer to report sections 2.2.4.3.1, 5.2 and Appendix I.) This results in a reduced number of eligible ACCUs.

As detailed in section 2.2.4.3, we understand that this has led to fewer new Victorian landfill gas projects being undertaken, and consequently less abatement occurring. Only one new landfill gas project has been registered in Victoria; all other Victorian projects were registered under GGAS and have been able to transition directly into the CFI/ERF[27]. The one new project that has been accredited in Victoria is yet to create an ACCU. Other states have multiple new (not transitioned from GGAS or Greenhouse Friendly) projects registered and creating ACCUs.

2.5.1.2 NSW Landfill Guide Requirements

From general industry knowledge, smaller New South Wales landfills generally did not capture gas and presumably did not have a specific requirement to do so, before the commencement of the Carbon Farming Initiative. However, the qualitative rule in the Methodology has been assumed to apply throughout New South Wales, setting a 30% baseline.

The guideline[28] suggests landfill gas capture should occur. Nevertheless, the guideline requirements have not been referenced in landfill licences (i.e. the licences do not require gas capture and management or reference the guideline). Rather, licences refer to legislative requirements (e.g. not to cause offsite odour). The strict interpretation of this provision could act as an additionality barrier for some smaller projects where, in practice, there are no particular constraints.

> Conclusion 9 The existing baseline arrangements in the Methodology may represent a barrier, particularly for potential projects in Victoria where a lower maximum parts-per-million (ppm) of methane concentration above the surface of the landfill, can result in a baseline greater than the default 30%.

2.5.2 Non-Carbon Tax Calculations

Under the landfill gas Methodology, the non-carbon tax emissions must be taken into account. For large sites, this calculation is a requirement under NGER. For a smaller landfill, which does not have to otherwise perform this analysis, the requirement of these calculations may present a barrier. A landfill may decide not to register a project if they believe the calculation requirements and the risks associated with reporting information subsequently deemed incorrect are too high.

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[27] ERF project register http://www.cleanenergyregulator.gov.au/ERF/project-and-contracts-registers/project-register accessed 31 August 2017.

[28] Environmental guidelines, solid waste landfills, Second edition, 2016. Environment Protection Authority. Available at www.epa.nsw.gov.au.

Example:

For a Victorian landfill opened in 2000 and which accepted 100,000 tonnes of default waste, for example, the % non-carbon tax emissions would be as tabulated below.

Table 10: Non-Carbon Tax Emissions Example

Year	Total emissions ($ktCO_2$-e)	Non-carbon tax emissions ($ktCO_2$-e)	% Non-carbon tax emissions
2015	44.7	36.7	82.0%
2016	46.7	39.1	83.6%
2017	48.6	41.3	85.0%
2018	50.4	43.6	86.3%

Undertaking this calculation involves using the Clean Energy Regulator's (CER) solid waste calculator to estimate emissions from each year of deposited waste within a claim, and then determining the percentage of emissions from waste not deposited during the carbon tax years[29].

Where landfills report under NGER, this calculation is not overly difficult, as the required information is already collected and collated, and such landfills are familiar with the solid waste calculator. For smaller sites that do not report under NGER, however, the data requirements may be onerous. The project participant must report annual tonnages, and the proportional split across waste type, since the landfill opened. The project proponent does not generally have access to this historical data, and it is often incomplete, based on low quality estimates, and difficult to compile to a standard acceptable to auditors.

Conclusion 10 The non-carbon tax emissions calculation requirement may present a barrier, particularly for small landfills which do not need to carry out this calculation for NGER reporting.

2.6 If not all projects under the method are likely to be additional, whether there is a subset or class of activities/project types which might remain additional.

Summary:

All landfill gas projects accredited are currently additional. An extension of the crediting period will enable emissions from these projects to continue to be optimally abated. Data available since the baseline calculations were designed in 2011 could be used to update the baseline calculation for any extended crediting period.

Based on the assessment performed to prepare this report, it appears that all currently accredited projects are additional. The additionality tests (i.e., newness, regulatory and government programs) are effective in accrediting projects that will create additional abatement.

[29] Carbon tax years spanned 1 July 2012 – 30 June 2014.

2.6.1 Baseline determination

The major issue for landfill gas projects regarding additionality is the determination of the baseline, and whether it is appropriate. As stated above, the authors believe that, across the industry, the current baselines are appropriate, but that going forward the determination of the baseline should be revisited. The parts per million (ppm) methane threshold concentration levels shown in Table 8 could represent baselines for the relevant States and Territories. Translating these requirements into a gas capture rate requirements can be performed using site-specific information. Information such as gas generation rates, landfill depth, and landfill cover types by area are needed, which are currently already required under the Methodology.

Legislative gas capture rates required for compliance could be investigated through performing a detailed assessment using:

- collated records of landfill gas compliance monitoring,
- reports or more general assessments of compliance, potentially done by a third party,
- knowledge of exceptions – landfills that have been non-compliant, and
- an informed opinion on general levels of compliance in their jurisdiction.

Each of these has parallels with Schedule 1 of the Methodology, and could better inform decisions on qualitative baselines.

Conclusion 11 The baseline determination is the major reflection of additionality for a landfill gas project. The current default baseline of 30% was evaluated in 2011. Data from projects in operation since then could be used to develop new baselines, particularly to determine additionality levels upon entering an extension period.

2.6.2 Continual capital investment for landfill gas projects

Landfill gas projects typically require continuous operating expenditure (i.e., landfill gas projects do not involve a once-off capital investment project). This continuous investment is required as landfill cells are developed on an ongoing basis throughout the landfill life. Once a cell is filled, a new cell is created and new waste is deposited. In large cells, additional infrastructure may be needed as the cell is filled. For a landfill gas project to continue to create abatement, the project needs to capture abatement from the new waste deposited in the landfill. This requires ongoing investment in new gas capture infrastructure (refer to section 6.3 for more information).

Gas collection infrastructure also requires ongoing maintenance, including the replacement of blocked wells. To incentivise abatement from new waste, the landfill gas project may need to create carbon credits or have income from the electricity generation. If these financial incentives are not available, landfill gas collection may decline to that needed to meet the minimum regulatory requirements (if any).

Conclusion 12 The continuous cell development process in landfills, means that ongoing investment is required if gas capture and management is to be maintained. If financial incentives such as from the creation of ACCUs and electricity generation (as applicable) are not available, gas collection and management may decline.

3 Assessment of whether the emissions removal or reduction, as the case may be, are measurable and capable of being verified

Summary:

The calculations set out in the landfill gas Methodology allow the abatement delivered by the project to be quantified. Equations utilised vary depending on the project type, therefore the use of calculations is tailored to different projects. The Methodology clearly sets out the equations and how these should be applied to quantify the volume of landfill gas sent to destruction devices. The volume of landfill gas sent to a destruction device is measured by robust scientifically based devices. The process of calculating the volume of methane destroyed is also robust.

There are some differences between the 2012 and 2015 Methodologies. This section distinguishes between the two Methodologies, where relevant. The 2015 Methodology is used as the basis for discussion with any differences with the 2012 Methodology either acknowledged in brackets or described in the subsequent sub-section.

3.1 Whether abatement delivered by eligible projects can be quantified using the calculation approaches set out in the method

Part 4 of the 2015 Methodology (Part 3 of the 2012 Methodology) and explanatory statement describe in detail how to calculate the net abatement that has occurred in an eligible project. There are many calculations that need to be conducted to determine how much abatement a project has achieved in each reporting period. In general, these calculations allow projects to quantify abatement using a consistent and scientifically robust approach that is verifiable. There are however some considerations from a measurement and verification perspective that are described below.

3.1.1 2015 Methodology considerations

Figure 8 (baseline abatement) and Figure 9 (project abatement) provide an overview of these equations for the 2015 Methodology. For the 2015 Methodology, the net abatement is calculated as the project abatement minus the baseline abatement. ACCUs are granted only for the abatement achieved in the project that goes beyond what would have been achieved without the project (i.e., the baseline abatement).

3.1.1.1 Baseline abatement

The baseline abatement is the methane combusted during the project and generated by non-carbon tax waste, multiplied by the proportion of methane that would have been combusted without the project. The determination of this proportion depends on the type of project. Equations 12 to 19 of the Methodology (Part 4 Division 4) are used to determine the baseline abatement. The main steps include determining the regulatory proportion, default baseline proportion and baseline proportion.

The baseline reduces the number of ACCUs the project receives, based on the volume of gas that would have had to be captured for regulatory purposes had the project not been accredited under the ERF. The application of the baseline effectively forms part of the *regulatory additionality test*. It determines how many ACCUs can be created based on how much gas would need to be captured to meet regulatory requirements. It is noted that it is not possible to capture all the gas from a landfill (refer to section 6.2). Regulatory requirements for gas capture vary greatly between jurisdictions and between sites, as described in section 2.1.3.

The regulatory proportion can be determined by following the guidance provided by the Methodology and the CER. The default baseline proportion represents qualitative regulatory requirements and is either 30 per cent or zero per cent. The baseline abatement is measurable and verifiable as the project proponent can provide the auditor with the relevant regulatory requirements applicable to the landfill. Evidence required for verification can include state or territory legislation, regulatory guidelines for the landfill, landfill licenses, etc. From a verification perspective, there is a potential detection risk[30], as it may not be possible to review all of the relevant regulatory requirements; however, it is the responsibility of the project proponent to provide the supporting information to justify the baseline proportion. Refer to section 4.2 for more information.

<u>Conclusion 13</u> The baseline abatement can be quantified using the calculation approaches set out in equations 12 to 19 of the Methodology. To assess this the equations in the Methodology (summarised in Figure 8) have been reviewed and allow quantification. The Methodology, explanatory statement, and guidance are sufficient for this to be calculated and verified.

3.1.1.2 Project abatement

The project abatement is calculated as the amount of methane (generated by non-carbon tax waste) combusted by the project minus the amount that would have been oxidised near the surface of the landfill had it not been collected during the project.

Equations 2 to 11 of the Methodology (Part 4 Division 3) are involved in calculations to determine project abatement. Figure 9 summarises these equations with further assessment of each equation and parameter included in Table 11. Each equation has been assessed as to whether it is quantifiable and verifiable. By reviewing each equation, it can be concluded that all parameters and equations can be quantified if the calculations and monitoring requirements are adhered to. For verification, it is important that the supporting data (including source, i.e., raw data) from all monitoring and measurement devices are retained.

[30] Detection risk is the audit risk that it may not be detected in the audit, i.e. it is possible that not all of the regulatory requirements are known by the auditor.

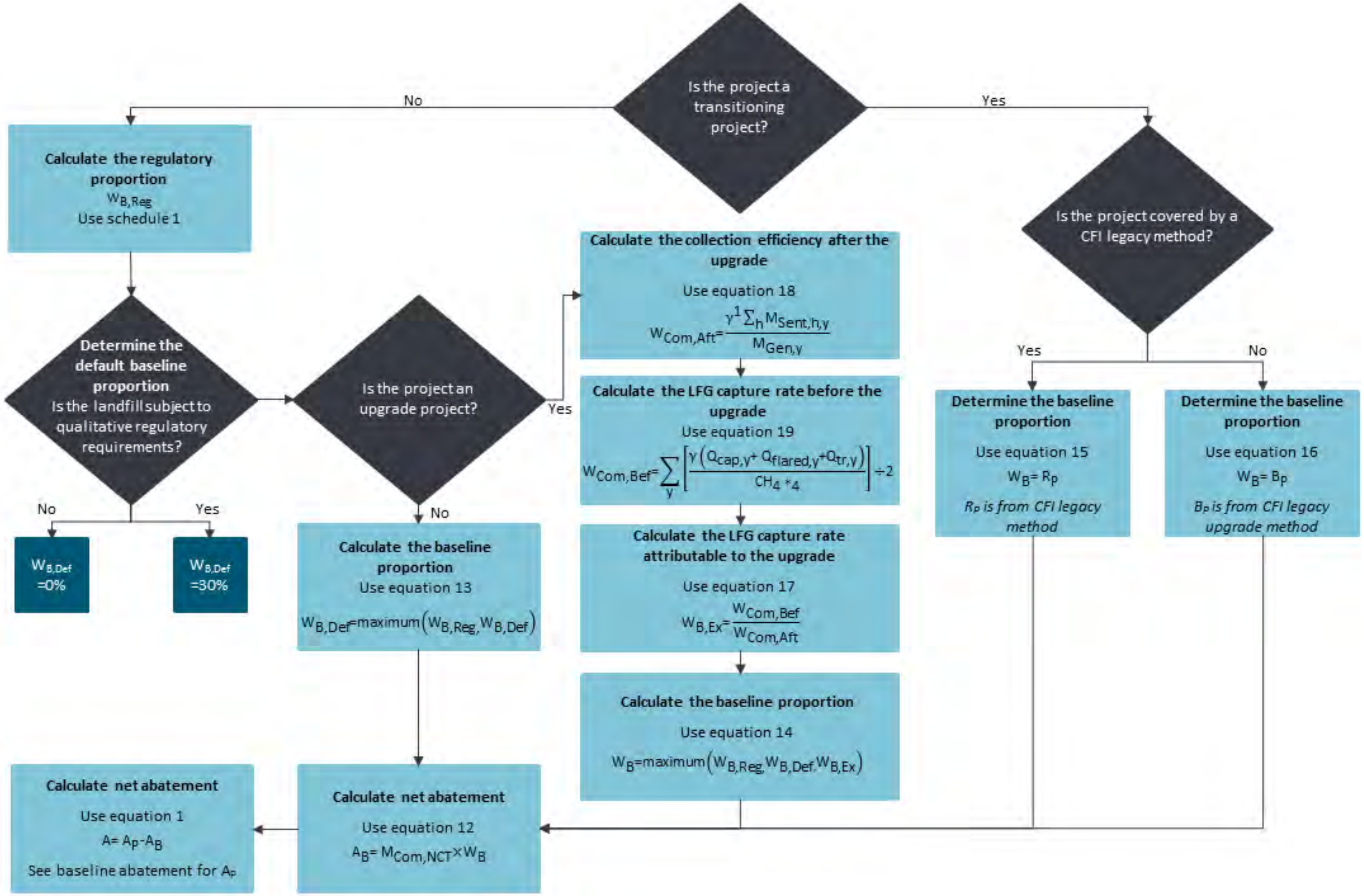

Figure 8: Equation flowchart – baseline abatement (CER, 2015)[31]

[31] Clean Energy Regulator (2015), "Participating in the Emissions Reduction Fund: A guide to the landfill gas method 2015", retrieved on 20 August 2017 from: http://www.environment.gov.au/climate-change/emissions-reduction-fund/methods/landfill-gas

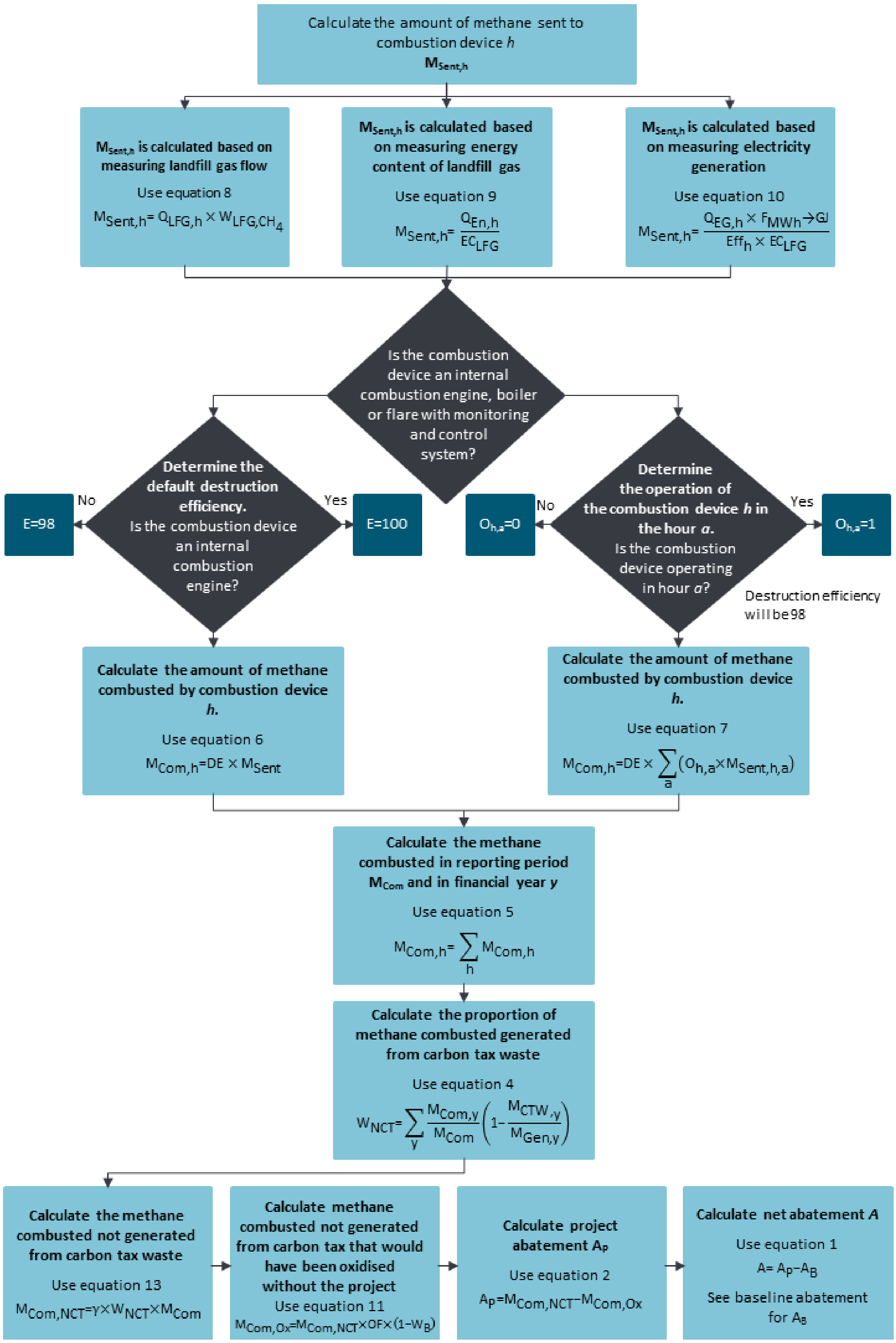

Figure 9: Equation flowchart – project abatement (CER, 2015)

Table 11: Assessment of quantification and verification of requirements (2015 Methodology)

Part	Equation number/ source (if applicable)	Parameter (if applicable)	Parameter description (if applicable)	Equation (if applicable)	Quantifiable?	Verifiable?
18	1	A	The carbon dioxide equivalent net abatement amount for the reporting period, in tCO_2-e	$A = A_P - A_B$	Yes - A_P is worked out using equation 2 and A_B is worked out using equation 12	Yes - if equations 2 and 12 are worked out correctly with the required supporting data from those equations.
20	2	Ap	The project abatement for the reporting period, in tCO_2-e	$A_P = M_{Com,NCT} - M_{Com,Ox}$	Yes - $M_{com,NCT}$ is worked out using equation 3 and $M_{com,Ox}$ is worked out using equation 11	Yes - if equations 3 and 11 are worked out correctly with the required supporting data from those equations.
	$M_{Com,NCT}$	$M_{Com,NCT}$	The methane combusted during the reporting period that was not generated from carbon tax waste, in tCO_2-e, worked out using equation 3	See equation 3		
	$M_{Com,Ox}$	$M_{Com,Ox}$	The methane combusted during the reporting period that was not generated from carbon tax waste and that, without the project, would have been oxidised in near surface conditions of landfill, in tCO_2-e, worked out using equation 11	See equation 11		
21	3	$M_{Com,NCT}$	See description above in equation 2	$M_{Com,NCT} = \gamma \times W_{NCT} \times M_{Com}$	Yes - γ is a standard unit conversion as described by NGER Measurement determination, W_{NCT} is worked out using equation 4, and M_{com} is worked out using equation 5	Yes - if equations 4 and 5 are worked out correctly and the NGER conversion factor applied in accordance with the Measurement Determination. Supporting data from equations 4 and 5 is required for verification.
		γ	Means the factor to convert cubic metres of methane at standard conditions to tCO_2-e worked out using subsection 5.4(1) of the NGER (Measurement) Determination			
		W_{NCT}	The proportion of the methane combusted during the reporting period that was not generated from carbon tax waste worked out using equation 4	See equation 4		

Part	Equation number/ source (if applicable)	Parameter (if applicable)	Parameter description (if applicable)	Equation (if applicable)	Quantifiable?	Verifiable?
		M_{Com}	The methane that was combusted during the reporting period, in cubic metres, worked out using equation 5	See equation 5		
22	4	W_{NCT}	See description above in equation 3	$W_{NCT} = \sum_{y} \frac{M_{Com,y}}{M_{Com}} \left(1 - \frac{M_{CTW,y}}{M_{Gen,y}}\right)$	Yes - W_{NCT} is quantifiable, however there are complexities associated with calculating this due to some potential issues with historical source data and landfill waste data quality (section 2.5.2). Quantification is possible through the use of the CER's ERF landfill gas calculator and the NGER solid waste calculator.	Yes - W_{NCT} is verifiable but it is likely there could be challenges with the source data quality, i.e. historical records of waste composition received at the landfill over past years may be limited or inaccurate. In some cases, it can be difficult to verify as there may not be sufficient and appropriate evidence to provide reasonable assurance.
		$M_{Com,y}$	The methane combusted in financial year y, in cubic metres, worked out using equation 5 as if a reporting period were a financial year	See equation 5		
		$M_{CTW,y}$	The methane generated by the landfill from carbon tax waste in financial year y in tCO_2-e calculated in accordance with subsection (2)			
		$M_{Gen,y}$	The methane generated by the landfill in financial year y, in tCO_2-e, calculated in accordance with subsection (3)			
23	5	M_{Com}	The methane combusted during the reporting period, in cubic metres.	$M_{Com} = \sum_{h} M_{Com,h}$	Yes - if the methane sent to combustion device h can be worked out using equation 8, 9 or 10. The operational hours must also be known for 'other combustion devices'.	Yes - if equations 8, 9 or 10 are worked out correctly with the required supporting data, e.g. gas flow meter data and methane concentration. The operational hours must also be known for 'other combustion devices'.
	6	$M_{com,h}$	If combustion device h is a boiler, a flare with monitoring and control system or an internal combustion engine, the methane combusted during the reporting period by the device, in cubic metres	$M_{Com,h} = DE \times M_{sent,h}$	Yes - if the methane sent to combustion device h can be worked out using equation 8, 9 or 10.	Yes - if equations 8, 9 or 10 are worked out correctly with the required supporting data from those equations. Of crucial

Part	Equation number/ source (if applicable)	Parameter (if applicable)	Parameter description (if applicable)	Equation (if applicable)	Quantifiable?	Verifiable?
		DE	The default methane destruction efficiency for a combustion device, which for an internal combustion engine is 1 and for any other combustion device is 0.98			importance is the measurement of methane sent to combustion device h.
		$M_{Sent,h}$	The methane sent to combustion device h during the reporting period, in cubic metres, worked out using equation 8, 9 or 10.	See equation 8, 9 or 10		
	7	$M_{com,h}$	If combustion device h is not a boiler, a flare with monitoring and control system or an internal combustion engine, the methane combusted during the reporting period by the device, in cubic metres	$M_{com,h} = DE \times \sum_a (O_{h,a} \times M_{Sent,h,a})$	Yes - if the methane sent to combustion device h can be worked out using equation 8, 9 or 10. The operational hours must also be known.	Yes - if equations 8, 9 or 10 are worked out correctly with the required supporting data from those equations. The operational hours must also be known. Of crucial importance is the measurement of methane sent to combustion device h.
		$O_{h,a}$	The operation of combustion device h in hour a, which is either 0 or 1			
		$M_{Sent,h,a}$	The methane sent to combustion device h in hour a, in cubic metres, worked out using equation 8 or 9			
24	8	$M_{Sent,h}$	*Option 1—using landfill gas sent to combustion device*	$M_{Sent,h} = Q_{LFG,h} \times W_{LFG,CH4}$	Yes - if $Q_{LFG,h}$ and $W_{LFG,CH4}$ are measured in accordance with monitoring requirements and/or NGER measurement determination	Yes - if $Q_{LFG,h}$ and $W_{LFG,CH4}$ are correctly measured with the required supporting data, i.e. gas flow measurement data from the monitoring and control system.
		$Q_{LFG,h}$	The landfill gas sent to the combustion device h during the period, in cubic metres			
		$W_{LFG,CH4}$	The proportion of the volume of the landfill gas that is methane			
24	9	$M_{Sent,h}$	*Option 2—using energy content of landfill gas sent to combustion device*	$M_{Sent,h} = \frac{Q_{En,h}}{EC_{LFG}}$	Yes - if $Q_{En,h}$ and EC_{LFG} are measured in accordance with monitoring	Yes - if $Q_{En,h}$ and EC_{LFG} are correctly measured with the required supporting

Part	Equation number/ source (if applicable)	Parameter (if applicable)	Parameter description (if applicable)	Equation (if applicable)	Quantifiable?	Verifiable?
		$Q_{En,h}$	The energy content of the landfill gas sent to the combustion device h during the period, in gigajoules		requirements and/or NGER measurement determination	data, i.e. energy measurement data from the monitoring and control system.
		EC_{LFG}	The energy content factor for landfill gas that is collected for combustion (methane only), in gigajoules per cubic metre			
	10	$M_{Sent,h}$	*Option 3—using electricity produced by internal combustion engine*	$M_{Sent,h} = \frac{Q_{EG,h} \times F_{MWh \to GJ}}{Eff_h \times EC_{LFG}}$		
		$Q_{EG,h}$	The electricity (supplied to the grid or used on-site) produced by internal combustion engine h during the period, in megawatt hours		Yes - if $Q_{EG,h}$ E_{ffh} and EC_{LFG} are measured in accordance with monitoring requirements and/or NGER measurement determination	Yes - if $Q_{EG,h}$ E_{ffh} and EC_{LFG} are correctly measured with the required supporting data, i.e. electricity measurement data from the monitoring and control system.
		$F_{MWh \to GJ}$	The factor to convert megawatt hours to gigajoules, which is 3.6			
		E_{ffh}	The factor for the electrical efficiency of internal combustion engine h			
		EC_{LFG}	The energy content factor for landfill gas that is captured for combustion (methane only), in gigajoules per cubic metre			
25	11	$M_{Com,Ox}$	The methane combusted during the reporting period that was not generated from carbon tax waste and that, without the project, would have been oxidised in near surface conditions of landfill, in tCO_2-e	$M_{Com,Ox} = M_{com,NCT} \times OF \times (1-W_B)$	Yes - $M_{com,NCT}$ is worked out using equation 3, OF is a default parameter and Wb relates to the baseline abatement worked out using equations 13 to 16	Yes - if equation 3 is correctly measured with the required supporting data, and the baseline abatement is determined correctly
		$M_{Com,NCT}$	The methane combusted during the reporting period that was not generated from carbon tax waste, in tCO_2-e	See equation 3		

Part	Equation number/ source (if applicable)	Parameter (if applicable)	Parameter description (if applicable)	Equation (if applicable)	Quantifiable?	Verifiable?
		OF	Means the oxidation factor for near surface methane in landfill set out in the definition of OF in subsection 5.4(1) of the NGER (Measurement) Determination			
		Wb	The proportion of the methane combusted in the reporting period that would have been combusted without the project worked out using whichever of equations 13 to 16 applies			
27	12	Ab	The baseline abatement for the reporting period, in tonnes CO_2-e	$A_B = M_{Com,NCT} \times W_B$	Yes - $M_{com,NCT}$ is worked out using equation 3 and Wb is worked out using whichever of equations 13 to 16 applies	Yes - if equations 3 and whichever of equations 13 to 16 are worked out correctly with the required supporting data obtained from equations 3 and 16.

There are some aspects of the calculation methods that can be complex and have the potential to make verification more difficult - for example:

- Calculation of the proportion of methane combusted that was generated from non-carbon tax waste (refer to section 2.5.2 for more information);
- Historical waste composition and volume data records, as required in the landfill gas model. Auditable records going back 20 years or more are often difficult to obtain or verify;
- Non-monitored periods can have uncertainties, depending on which instruments or meters were the source of malfunctions (i.e. not working correctly or still operating). It may be possible to estimate a parameter using alternative data or information, for example:
  - electricity generation could be used to estimate gas flow if the engine efficiency is known. So, if a gas flow meter is broken, a non-monitored period may still be verifiable. However, if the gas is flared but the composition or flow rate is not known, verification is more difficult.
- Operation of combustion device *h* during hour *a* requires at least 40 minutes of operation. However, data loggers may work on 10, 15 or 20 minutes. Consequently, incorrect or failed measurements could be difficult to verify (refer to section 3.2.1.1).

Nonetheless, as various data is required to be collected in order to perform the calculations required in the Methodology, this data provides the basis for the quantification of abatement and gives a fully verifiable method.

Table 11 describes the equations and highlights the key parameters that need to be accurately monitored so the abatement can be quantified and verified. Further assessment of the monitoring, measurement and data collection is provided in response to the subsequent sections of the report.

Conclusion 14 By conducting a detailed review of all of the equations and parameters in the 2015 Methodology (summarised in Table 11), it is clear that the abatement delivered by eligible projects can be quantified using the calculation approaches set out in the Methodology. Net abatement in the Methodology is fully verifiable if the equations have been worked out correctly and the supporting data for each parameter is available.

3.1.2 2012 Methodology considerations

The 2012 Methodology essentially follows a very similar calculation approach as the 2015 Methodology. There are however some minor differences in the system boundary (see section 4.1.4) and therefore some additional parameters are required for the 2012 Methodology. In addition, the names and symbols used for the measured/monitored parameters have some differences (see section 3.2 and section 4.1.3). As with the 2015 Methodology, the calculations defined in the projects allow projects to quantify abatement using a consistent and scientifically robust approach that is verifiable. Table 12 assesses the equations and highlights the key parameters that need to be accurately monitored so the abatement can be quantified and verified.

Table 12: Assessment of quantification and verification of requirements (2012 Methodology)

Equation number/source (if applicable)	Parameter (if applicable)	Parameter description (if applicable)	Equation (if applicable)	Quantifiable?	Verifiable?
1	A	The net abatement amount for an offsets project to which this Methodology Determination applies for a reporting period, in tCO_2-e	$A = (A_p - Y_p)$	Yes - once A_p and Y_p are calculated	Yes - this requires A_p and Y_p to be calculated
2	A_p	Quantity of emissions avoided as a consequence of the project, in tCO_2-e	$A_p = \left[\left(\gamma \sum_{h=1}^{n} Q_{com,h}\right) - A_{reg}\right] \times (1 - OF) - E_{com}$	Yes - if data available for $Q_{com,h}$	Yes - if data available for $Q_{com,h}$
2(a)	A_p	Quantity of emissions avoided as a consequence of the project, in tCO_2-e	$A_p = \left[\left(\gamma \sum_{h=1}^{n} Q_{com,h}\right) + A_{com,ice} - A_{reg}\right] \times (1 - OF) - E_{com}$	Yes - if data available for $Q_{com,h}$	Yes - if data available for $Q_{com,h}$
3 (flares)	$\sum_{h=1}^{n} Q_{com,h}$	Volume of methane generated by legacy waste destroyed by combustion device h, in cubic metres	$Q_{com,h} = Q_{sent,h} \times DE_h \times L_p$	Yes - if data available for $Q_{sent,h}$	Yes - if data available for $Q_{sent,h}$
3 (internal combustion engine)		Volume of methane generated by legacy waste destroyed by combustion device h, in cubic metres	$Q_{com,h} = Q_{sent,h} \times DE_h \times L_p$	Yes - if data available for $Q_{sent,h}$	Yes - if data available for $Q_{sent,h}$
4a	$Q_{sent,h}$	Volume of methane sent to combustion device h, in cubic metres	$Q_{sent,h} = Q_{lfg,h} \times W_{CH_4}$	Yes - if data available for $Q_{lfg,h}$	Yes - if data available for $Q_{lfg,h}$
4b	$Q_{sent,h}$	Volume of methane sent to combustion device h, in cubic metres	$Q_{sent,h} = E_{lfg} \times \frac{1}{EC_{biogas}}$	Yes - if data available for E_{lfg}	Yes - if data available for E_{lfg}
5	E_{com}	Quantity of methane emissions and nitrous oxide emissions released from all combustion devices, in tCO_2-e	$E_{com} = E_{rel,CH_4} + E_{N_2O}$	Yes - this uses NGER emission factors	Yes - if volume of methane destroyed is known
6	$E_{rel,CH4}$	Quantity of methane emissions from legacy waste released from all combustion devices, in tCO_2-e	$E_{rel,CH_4} = \gamma \sum_{h=1}^{n} Q_{rel,h} \times OF$	Yes - this requires $Q_{rel,h}$ to be calculated	Yes - if data available for $Q_{rel,h}$

Equation number/source (if applicable)	Parameter (if applicable)	Parameter description (if applicable)	Equation (if applicable)	Quantifiable?	Verifiable?
6(a)	$E_{rel,CH4}$	Quantity of methane emissions from legacy waste released from all combustion devices, in tCO_2-e	$E_{rel,CH_4} = \left[\left(\gamma \sum_{h=1}^{n} Q_{rel,h}\right) + \left(\left(\sum_{h=1}^{n} QE_h \times (1 - DE_h)\right) \times CH_4 factor \times GWP_{CH_4} \times L_p\right)\right] \times OF$	Yes - this requires $Q_{rel,h}$ and QE_h to be calculated	Yes - if $Q_{rel,h}$ and QE_h calculated correctly
7	$\sum_{h=1}^{n} Q_{rel,h}$	Volume of methane generated from legacy waste not destroyed by combustion device h, in cubic metres	$Q_{rel,h} = Q_{sent,h} \times L_p - Q_{com,h}$	Yes - if data available for $Q_{sent,h}$ and $Q_{com,h}$	Yes - if data available for $Q_{sent,h}$ and $Q_{com,h}$
8	E_{N_2O}	Quantity of nitrous oxide emissions released from legacy waste as a result of methane destruction processes from all combustion devices, in tCO_2-e	$E_{N_2O} = \sum_{h=1}^{n} Q_{sent,h} \times EC_{biogas} \times \frac{EF_{N_2O}}{1{,}000} \times L_p$	Yes - N_2O emissions legacy waste fraction	Yes - N_2O emissions legacy waste fraction
8(a)	E_{N_2O}	Quantity of nitrous oxide emissions released from legacy waste as a result of methane destruction processes from all combustion devices, in tCO_2-e	$E_{N_2O} = \left(\left(\sum_{h=1}^{n} Q_{sent,h} \times EC_{biogas}\right) + \sum_{h=1}^{n} QE_h\right) \times \frac{EF_{N_2O}}{1{,}000} \times L_p$	Yes - as above using energy content	Yes - as above using energy content
9	$A_{com,ice}$	Quantity of methane generated by legacy waste destroyed as a consequence of combustion in an internal combustion engine, in tCO_2.e	$A_{com,ice} = \left(\sum_{h=1}^{n} Q_{E_h} \times DE_h\right) \times CH_4\ factor \times GWP_{CH_4} \times L_p$	Yes - this just requires the other parameters	Yes - the parameters need to be reviewed
10	QE	Energy content of the methane sent to the internal combustion engine h, in gigajoules (GJ)	$QE_h = \frac{Ep_h \times E_{GJ}}{Eff}$	Yes - this just requires the other parameters	Yes - the parameters need to be reviewed
11	L_p	The proportion of methane generated from legacy waste	$L_p = \frac{M_{lw}}{M_{lw} + M_{plw}}$	Yes - although legacy waste is reliant on historical landfill data quality	Yes - however historical landfill data can be difficult to verify

Equation number/source (if applicable)	Parameter (if applicable)	Parameter description (if applicable)	Equation (if applicable)	Quantifiable?	Verifiable?
12(a)	A_{reg}	The quantity of methane destroyed under baseline conditions, due to regulatory requirements in tCO_2-e	$A_{reg} = \left(\gamma \sum_{h=1}^{n} Q_{com,h} + A_{com,ice}\right) \times R_p$	Yes - $Q_{com,h}$ and $A_{com,ice}$ require the quantity of methane destroyed to be measured	Yes - if supporting data is available for $Q_{com,h}$ and $A_{com,ice}$
13	Y_p	Emissions from fuel and grid-delivered electricity used to operate the landfill gas extraction system to capture and destroy methane generated from legacy waste as a result of the project, in tCO_2-e	$Y_p = Y_t - Y_{reg}$	Yes - see below	Yes - see below
14	Y_t	Total emissions from fuel and grid-delivered electricity used to operate the landfill gas extraction system, in tCO_2-e	$Y_t = (E_f + E_{elec}) \times L_p$	Yes - see below	Yes - see below
15	Y_{reg}	The emissions from fuel and grid-delivered electricity used to operate the landfill gas extraction system to meet regulatory requirements, in tCO_2-e	$Y_{reg} = Y_t \times R_p$	Yes - if Y_t has been calculated	Yes - if Y_t and R_p have supporting data
16	E_f	Total emissions from fuel used (including supplemental natural gas) to operate the landfill gas extraction system, in tonnes of CO_2-e	$E_f = \sum_{i=1}^{n} \sum_{j=1}^{N} E_{ij}$	Yes	Yes - the quantity of fuel can be agreed to invoices/measuremen t
17	$\sum_{i=1}^{n} \sum_{j=1}^{N} E_{ij}$	Emissions from fuel type (i) of greenhouse gas (j) in tonnes of CO_2-e	$E_{ij} = \frac{Q_i \times EC_i \times EF_{ijoxec}}{1{,}000}$	Yes - this uses NGER emission factors	Yes - the quantity of fuel can be agreed to invoices/measuremen t
18	E_{elec}	Total emissions from consumption of purchased electricity used to operate the landfill gas extraction system, in tonnes of CO_2-e	$E_{elec} = Q_{elec} \times \frac{EF}{1{,}000}$	Yes - this uses NGER emission factors	Yes - if quantity of electricity can be agreed to meter data

Equation number/source (if applicable)	Parameter (if applicable)	Parameter description (if applicable)	Equation (if applicable)	Quantifiable?	Verifiable?
Measured (section 10)	$Q_{lfg,h}$	Volume of landfill gas sent to combustion device h, in cubic metres	NA	Yes	Yes
Section 10: measured or default (0.5)	$W_{CH4,h}$	The average methane fraction of the landfill gas, calculated using either a default value of 0.5, or measured	NA	Yes	Yes
Measured	$E_{lfg,h}$	The value, calculated by a flow computer, of the energy content of methane in the landfill gas, in gigajoules (GJ)	NA	Yes	Yes
NGER Determination Section 5.4 (1)	EC_{biogas}	The energy content factor for landfill biogas that is captured for combustion as stated in Schedule 1, Part 2 of the *NGER Measurement Determination*	NA	Yes	Yes
NGER Determination Section 5.4 (1)	OF	Oxidation factor for near surface methane in a landfill as stated in Part 5.2 of the *NGER Measurement Determination*	NA	Yes	Yes
Estimate using Regulatory Baseline Guidelines. Defaults: GGAS = 0.24; GF = 0	R_P	The proportion of methane that is required to be captured or destroyed to meet regulatory requirements	NA	Yes	Yes
NGER Solid waste calculator; NGER Determination Part 5.2	M_{lw}	The quantity of methane generated by legacy waste during that part of the reporting period that is after 1 July 2012, in tCO_2-e, calculated using a method specified in Divisions 5.2.2 to 5.2.4 of the *NGER Measurement Determination*	NA	Yes	Yes

Equation number/source (if applicable)	Parameter (if applicable)	Parameter description (if applicable)	Equation (if applicable)	Quantifiable?	Verifiable?
NGER Solid waste calculator; NGER Determination Part 5.2	M_{plw}	The quantity of methane generated by non-legacy waste during that part of the reporting period that is after 1 July 2012, in tCO_2-e, calculated using a method specified in Divisions 5.2.2 to 5.2.4 of the *NGER Measurement Determination*	NA	Yes	Yes
Section 10: measured or default (0.98)	DE_h	Methane destruction efficiency for combustion device h, expressed as a fraction. If the combustion device is an open flare, a default value of 0.98 must be used. Otherwise, either a default value of 0.98 may be used or the methane destruction efficiency of the device can be determined in accordance with section 3.14. If the device is a flare and the flare is not operational, DE_h is zero	NA	Yes	Yes

Conclusion 15 Abatement delivered by eligible projects can be quantified using the calculation approaches set out in the Methodology. This is dependent on the project proponent collecting and appropriately applying the required data. This conclusion is supported by reviewing all the equations and parameters required in the Methodology. As such, the following is confirmed:

- The calculation approaches are straightforward and mathematically robust.
- The net abatement calculations are an accurate representation of reality.
- The Methodology focused on direct measurement of the key parameters that determine the ACCUs (i.e. the quantity of methane sent to (and destroyed by) the combustion device *h)*.
- The 2012 and 2015 Methodologies will yield approximately the same output if the same options (e.g. selecting the default, not measurement data) are selected.
- However, the two Methodologies differ in the circumstances in which different options may be selected and have slightly different system boundaries and parameter requirements.
- Nonetheless if the project proponent follows the equations outlined in the Methodology the net abatement can be accurately calculated.
- The calculated abatement is fully verifiable if the project proponent has followed the requirements for monitor, measurement and data collection (as assessed in section 3.2)

3.2 Whether requirements in the method for monitoring, measurement and data collection: (i) are appropriate and scientifically/technically valid; (ii) are adequately specified; and (iii) use references to external sources in an accurate and appropriate way.

There are considerable differences between the 2012 and 2015 Methodology in relation to the monitoring, measurement and data collection. Each Methodology has been addressed in a separate section.

3.2.1 2015 Methodology considerations

3.2.1.1 Monitoring and Measurement

The 2015 Methodology (Part 5 Division 2) lists the five parameters used in calculating net abatement amounts that require monitoring. It is noted that not all of these parameters will necessarily apply to a project.

Monitoring requirements are listed in Section 33 of the Methodology (refer to Table 13). The requirements include the process for monitoring and the standard to which it must adhere. A requirement is that measurement procedures are in accordance with relevant NGER (Measurement) Determination specifications which is appropriate and scientifically/technically valid.

If there are no relevant NGER specifications, then a monitored parameter must meet appropriate measuring requirements. In most cases this is specified by the measuring equipment manufacturer technical specification.

The Methodology requires that any equipment or device used to monitor a parameter must be calibrated by an accredited third-party technician at intervals, and using methods, that are in accordance with the manufacturer's specifications. This requirement provides a rigorous scientific approach in theory, and in practice for concentration measurement (typically a gas chromatograph). Nevertheless, it is less usable in practice for flow, temperature and pressure instruments. This is because manufacturers for these instruments may not specify a calibration frequency. The instruments will be calibrated when they leave their factory, however, the manufacturers usually do not provide guidance on calibration frequency for certain applications such as landfill gas measurement installations. Landfill gas can be moist, contain dirt particles and microbiological content.

Table 13 shows that the monitoring and measurement requirements are adequately specified, and section 33 uses references to external sources in an accurate and appropriate way.

Table 13: Requirements to monitor certain parameters (2015 Methodology)

No	Parameter	Description	Unit	Measurement procedure (including frequency as required)	Determination of parameter from measurements
1	$Q_{En,h}$	Energy content of the landfill gas sent to combustion device h	GJ	Estimated under Division 2.3.6 of the NGER (Measurement) Determination or section 6.5 of that Determination using measurement criteria AAA.	Cumulative value for reporting period
2	$O_{h,a}$	Operation of combustion device h during hour a	1 or 0	If the combustion device is a flare, operation is determined for each minute using temperature measurement.	For the purpose of calculating $M_{com,h}$ in equation 7 (above), the value of $O_{h,a}$ determined for an hour based on the operation of the combustion device must be paired to the cumulative value of $M_{sent,h}$ for the same hour
				If temperature is measured at 500 degrees Celsius or higher for 40 minutes or more in an hour, then $O_{h,a}$ = 1. Otherwise $O_{h,a}$ = 0.	
				For all other combustion devices, operation for each minute is to be determined in accordance with manufacturer's specifications.	
				If the device operates according to manufacturer's specifications for the entire hour then $O_{h,a}$ = 1. Otherwise $O_{h,a}$ = 0.	
				All measuring equipment must be used in accordance with appropriate measuring requirements	
3	$Q_{LFG,h}$	Landfill gas sent to combustion device h	Cubic metres	Estimated under Division 2.3.6 of the NGER (Measurement) Determination using measurement criteria AAA.	For equation 7, cumulative values for a time interval not greater than 1 hour must be paired to measurements of $W_{LFG,CH4}$ for the time interval.
				Frequency—continuously	Otherwise, the measurements must be paired to measurements of $W_{LFG,CH4}$ for the same measurement interval

No	Parameter	Description	Unit	Measurement procedure (including frequency as required)	Determination of parameter from measurements
4	$Q_{EG,h}$	Electricity (supplied to the grid or used on-site) generated by internal combustion engine h	MWh	Estimated under Part 6.1 of the NGER (Measurement) Determination.	Cumulative value for the reporting period
				Measure only the electricity produced from the combustion of landfill gas (not from the combustion of other fuel types)	
5	$W_{LFG,CH4}$	Fraction of the volume of landfill gas that is methane	Fraction	Estimated under Division 2.3.6 of the NGER (Measurement) Determination.	For the purpose of equation 7, average values for a time interval not greater than 1 hour must be paired to measurements of $Q_{LFG,h}$ for the time interval.
				Frequency—continuously.	Otherwise, the measurements must be paired to measurements of $Q_{LFG,h}$ for the same measurement interval
				Measured at the same conditions as $Q_{LFG,h}$	Landfill gas contains moisture, typically from 2% to 7% on a mass basis. Flow measurement is usually done on the moist gas, but concentration measurement using a gas chromatograph is done on dried gas (because the instrument cannot handle moisture). Because water has a molecular weight different from methane and air components such as nitrogen and oxygen, multiplying the moist flow rate times the dry methane concentration will not give an accurate methane flow rate; it will be overstated by the 2% to 7% range referred to above. The Methodology is silent on how this is to be handled.

Further assessment of each of the parameters is assessed as follows:

$Q_{En\ h}$ – Energy content of the landfill gas sent to combustion device h

The energy content of landfill gas using equation 9 is estimated under Division 2.3.6 of the NGER (Measurement) Determination or section 6.5 using measurement criterion AAA. Either of these approaches follows widely applied measurement techniques.

$O_{h\ a}$ – Operation of combustion device h during hour a

If the combustion device is a flare, operation is determined continuously or continually depending on the type of UV or temperature sensor in use. The 2015 Methodology in section 5 requires "the combustion process ... [be one] which can be monitored on a minute by minute basis", and in section 33 item 2 requires if temperature is measured then temperature must be "500 degrees Celsius or higher for 40 minutes or more in an hour". Similarly, the 2012 Methodology requires in section 3.18 "If flare operation is detected using temperature measurement, then the flare is taken not to be operational and the destruction efficiency taken to be zero in any particular hour if there is no record of the temperature of the exhaust gas of the flare or the recorded temperature is less than 500°C for any period exceeding 20 minutes in that hour."

Verification of these requirements is made difficult by the almost universal use of data loggers which record parameters such as temperatures each (typically) 10, 15 or 20 minutes. It is unclear whether, for example, a failure (less than 500 degrees Celsius) of two temperature values 10 minutes apart should result in a loss of claim for that hour. All that is certain is that (for this example) the temperature was unsatisfactory for some time around each of the time points ten minutes apart, and likely for between 10.1 and 29.9 minutes. Verification usually involves the creation of an algorithm such as 'fail if any two -10 minute data values are below 500°C'. The algorithm details are usually debated between the auditors and the proponents.

The effect of these issues is unlikely to be material to the abatement calculations but should be considered from a technical verification perspective.

For all other combustion devices, operation for each minute is to be determined in accordance with the manufacturer's specifications. If the device operates according to manufacturer's specifications for the entire hour then $O_{h,a} = 1$, otherwise $O_{h,a} = 0$. This effectively means that if a combustion device does not operate for a small length of time (seconds or minutes) then zero (0) operating time is recorded for that hour. This is likely to lead to an underestimation of calculated abatement.

$Q_{LFG\ h}$ – Landfill gas sent to combustion device *h*

The energy content of landfill gas using equation 8 is estimated under Division 2.3.6 of the NGER (Measurement) Determination using measurement criterion AAA, which is appropriate and an accurate measurement approach.

$Q_{EG,h}$ – Electricity (supplied to the grid or used on site) generated by internal combustion engine *h*

Electricity generated from internal combustion engines is estimated under Part 6.1 of the NGER (Measurement) Determination. This follows widely applied industry standards and is appropriate.

Since this only measures the electricity produced from the combustion of landfill gas (not from the combustion of other fuel types) there is a detection risk if other fuels are used by the engine but not appropriately recorded. For example, diesel or natural gas could be used for start-up fuel and would therefore need to be excluded from the abatement calculations.

$W_{LFG,CH4}$ – Fraction of the volume of landfill gas that is methane

The methane fraction of landfill gas is estimated under Division 2.3.6 of the NGER (Measurement) Determination. Landfill gas contains moisture, estimated for one ERF project as ranging on a 95% confidence interval from 2.3% (gas at 23°C in winter) to 7.5% (gas at 38°C in summer) on a molar (and therefore approximately on a volume) basis[32]. Flow measurement is usually done on the moist gas, but concentration measurement using a gas chromatograph is done on dried gas (because the instrument cannot handle moisture). Because water has a molecular weight different from methane and air components such as nitrogen and oxygen, multiplying the moist flow rate times the dry methane concentration will not give an accurate methane flow rate it will be overstated (by in the case above the 2.3% to 7.5% range referred to). The Methodology is silent on how this is to be handled.

Conclusion 16 Measuring requirements are defined as being consistent either with NGER (Measurement) Determination specifications or with estimates or relevant standards and other requirements under the *National Measurement Act 1960*. This is considered to be scientifically and technically robust as Australian Standards must be adhered to. The Methodology clearly specifies these requirements and makes references to external sources in an accurate and appropriate way.

3.2.1.2 Data Collection

The 2015 Methodology does not summarise the data collection requirements in the same level of detail as the 2012 Methodology (Division 3.3). However, these requirements are implicit in compliance with the Methodology (i.e., for a verifiable project, it is necessary to perform measurements and collect data as specified in the Methodology).

Conclusion 17 As the 2015 Methodology does not clearly specify the data collection requirements it can be concluded that they are not adequately specified.

3.2.2 2012 Methodology considerations

As previously mentioned, the 2012 Methodology (Division 3.3) provide more detail on the data collection requirements than the 2015 Methodology. Moreover, the requirements are considered scientifically/technically robust in general. Parameters that are outlined in section 3.14 (measurement procedures and measurement frequency) are assessed as follows:

$Q_{sent\ h}$ – Quantity of landfill gas sent to a combustion device *h*

This is equivalent to $Q_{LFG,h}$, under the 2015 Methodology and must be measured by a flow meter, corrected to standard conditions. Data is required to be aggregated monthly and yearly using continuous measurement frequency which is scientifically robust.

[32] The water content of the landfill gas has been estimated using a computerised simulation used by Australian universities and gas companies, with data from an ERF project, and reported in unpublished "Equations for Water Content and Properties of Gas", Prof V. Rudolph, University of Queensland, 06 May 2013.

DE – Methane destruction efficiency for device *h*

In most cases, it is expected that projects would apply the 0.98 default factor. Nevertheless, with enclosed flares and internal combustion engines, there is the option to perform measurement by a NATA accredited emission stack testing company. This must use a methodology based on the US EPA Method 18[33]. This would be expected to produce more accurate results than using the default value however, as a project can choose whether to measure DE or use the default factor, there is a risk of 'gaming' (i.e., applying the more beneficial destruction efficiency). It is noted that under the 2015 Methodology, the destruction efficiency has been changed to use the default values only.

W_{CH4} – Methane fraction in the landfill gas

Gas composition analysers are widely used in landfill gas collection systems and may be used in ERF projects, but are not compulsory. Under the 2012 Methodology, it is possible to apply the default methane concentration of 50%. Whilst this is likely to be a reasonable estimate, it is possible to operate a flare with methane concentrations lower than 40. Measuring the methane concentration is better than using a default value but either approach is quantifiable and verifiable.

Electricity (Q_{elec}) – Quantity of electricity used for abatement activity

The electricity used can be measured using the relevant meter and sub-meter values, or estimated from the invoiced amount of electricity supplied to the landfill. The use of submeter data is likely to be more accurate than estimates from invoiced amounts. With either approach, there are complications in assessing how much electricity is used by the abatement activity and other landfill activities unless appropriate sub-metering is in place. Nevertheless, electricity use is not expected to be a material amount in relation to the total abatement calculated in projects.

Fuel used (Qi) – Quantity of fuel used for abatement activity

For each fuel used for abatement activities, the amount of fuel must be estimated as a proportion of the total fuel used for the facility. The estimation can be made using readings from a meter or from invoices which is a robust approach scientifically. Manufacturer's specifications must be used to estimate the proportion of total fuel used for the facility. Consequently, the quantity of fuel used is expected to be reasonably accurate.

E_{Ph} – Quantity of electricity produced by combustion in internal combustion engine generator *h*

Electricity produced metered data can be used in the Methodology. This data can either be:

- electricity exported to the grid; or
- meter data from an internal combustion engine generator (if electricity is used onsite).

Since the accuracy of the meter used must be equivalent to a revenue meter (i.e. used for commercial transactions). This is considered to be technically sound and would meet the highest industry standards.

[33] US Environmental Protection Agency, Air Emission Measurement Center (EMC), Method 18 Measurement of gaseous organic compound emissions by gas chromatography, retrieved from: https://www.epa.gov/emc/method-18-volatile-organic-compounds-gas-chromatography.

Electrical efficiency factor (Eff) – The electrical efficiency factor of the internal combustion engine generator

The Eff can be determined by either:

- as specified by the internal combustion engine manufacturer (with reference to Australian Standard AS 4594.1 or equivalent); or
- using the default value of 36% (factor of 0.36).

Electrical efficiency can vary between different engine types, how well they are operated and maintained, and the load factor at which they are operated. All engines would be expected to have a technical specification, therefore it is not clear why the use of a default value of 36% would be appropriate (refer to section 4.1.3.3).

Volumetric measurement — Quantity of landfill gas ($Q_{lfg\ h}$) and methane fraction (W_{CH4}), flow computer requirements, and gas composition

Sections 3.15 to 3.17 of the 2012 Methodology follow robust scientific methods and adhere to commonly applied national and international standards. The description of quantity of landfill gas, methane concentration, and flow computer requirements are adequately specified and use references to external sources in an accurate and appropriate way.

Instruments must be calibrated to manufacturer specifications. Nevertheless, manufacturers generally do not specify calibration frequency for flow, temperature and pressure instruments. Furthermore, specifications may not be fully valid for landfill gas conditions (e.g. landfill gas can be moist, contain dirt particles and microbiological content).

Operation of flares

Methodology considerations in the case of operation of flares is addressed in section 3.2.1.1.

3.2.3 Measurement methods and the use of default values

The primary measurement methods used in the landfill gas Methodologies include:

- Measurement of methane sent to a combustion device (flow and concentration).
- Measurement of energy content of landfill gas sent to combustion device.
- Measurement of electricity produced by a landfill gas engine.

There are also several parameters within the landfill gas methods where default factors can be used.

- Default methane percentage.
- Destruction efficiency of flares and engines.
- Global warming potential of methane.
- Energy content of landfill gas.
- Oxidation factor.
- Electrical efficiency of engines (for electricity generation).

The use of default factors is common is many carbon abatement calculations. However, the choice of default values can impact the calculated abatement. It is therefore important that where default values are required that these are appropriate both scientifically and technically. These considerations are assessed for the most important default factors as follows:

3.2.3.1 Default methane percentage

Please refer to section 2.2.1.1 for background information. Whilst verification of the mathematical impact of the use of a 50% factor is straightforward, audit to reasonable assurance level of this parameter is challenging. Furthermore, a qualified opinion may be issued where the default 50% methane concentration is being used, when an average methane content may be below that value.

3.2.3.2 Oxidation factor

The oxidation factor of 10% is aligned with the Clean Development Mechanism (CDM), however the evidence is inconclusive if this is appropriate as discussed in section 4.1.3. More detail can also be found in section 4.1.5.4.

3.2.3.3 Other default factors

Verification of the mathematical impact of the use of the other five default factors (i.e. destruction efficiency of flares and engines, GWP of methane, energy content of landfill gas, oxidation factor and electrical efficiency of engines) is straightforward. Audit to reasonable assurance level of these parameters is also generally straightforward. Because the default values follow international guidelines or NGER Act determinations, they are considered appropriate.

3.2.3.4 Non-Carbon Tax percentage

Please refer to section 2.2.3 for background information. Verification of the exclusion of emissions from waste deposited during the carbon tax years is challenging if historical waste tonnes records are incomplete or lack credibility (e.g. if the data presents large increases or decreases from year to year).

3.2.3.5 Baselines

As noted in section 3.1.1.1, verification of baselines can be time consuming and present a detection risk as it may not be possible to review all relevant regulatory requirements. Refer to section 4.2 for more information.

Conclusion 18 There are some differences and similarities between the 2012 and 2015 Methodologies. The areas of least rigour are:

a) The ability to use a default concentration of 50% (if measurement not already in use in the 2015 Methodology, and at any time in the 2012 Methodology).

b) Electrical efficiency can vary between different engine types, how well they are operated and maintained, and the load factor at which they are operated. All engines would be expected to have a technical specification. Therefore, it is not clear why the use of a default value of 36% would be appropriate.

c) Instruments must be calibrated to manufacturer specifications. Nevertheless, manufacturers generally do not specify calibration frequency for flow, temperature and pressure instruments. Furthermore, specifications may not be fully valid for landfill gas conditions (landfill gas can be moist, contain dirt particles and microbiological content).

Conclusion 19 The calculations set out in both the 2012 and 2015 Methodology allow the abatement delivered by the project to be quantified through the use of scientific measurements. Equations used vary depending on the project type so the use of calculations is tailored to different projects. The volume of landfill gas sent to a destruction device is measured by robust scientifically based devices. The process of then converting landfill gas to volume of methane and amount of methane destroyed is also robust as this uses common methods for destruction efficiency. This excepts the use of some of the default values. In general, the default values are conservative and do not have a material influence on calculated abatement.

Conclusion 20 The Methodologies clearly set out the equations and how these should be applied to quantify the volume of landfill gas sent to destruction devices.

Conclusion 21 By reviewing the Methodologies, it can be concluded that the measurement and monitoring requirements refer to external references where appropriate and required.

3.3 Whether reasonable steps have been taken to minimise uncertainty in measurement and data collection associated with the method.

The Methodology has clearly taken reasonable steps to minimise uncertainty in measurement and data collection. Most measurement requirements are relatively straightforward and reduce uncertainty (e.g. gas flow measurements need to be within strict uncertainty limits). With the measurement of gas flow and methane concentration there is some inherent uncertainty as specified by manufacturer measurement devices.

In the 2012 Methodology, the measurement of landfill gas must be carried out using equipment that complies with the following accuracy and transmitter requirements:

a) Pressure < ±0.25%.

b) Differential Pressure < ±0.25%.

c) Temperature < ±0.50%.

The 2015 Methodology does not specify the accuracy and transmitter requirements. However, this can be derived from the relevant standards and manufacturer specifications. The requirements in both the 2012 and 2015 Methodologies to perform regular calibrations of gas flow meters and continuous methane analysers ensures that uncertainty is minimised for landfill gas measurement. However, as concluded above (refer to section 3.2.1), manufacturers usually do not specify calibration frequency for flow, temperature and pressure instruments, and any specifications may not be fully valid for landfill gas conditions which could lead to uncertainty.

Landfill gas contains moisture, estimated for one ERF project as ranging on a 95% confidence interval from 2.3% (gas at 23°C in winter) to 7.5% (gas at 38°C in summer) on a molar (and therefore approximately on a volume) basis[34]. Flow measurement is usually done on the moist gas, but concentration measurement using a gas chromatograph is done on dried gas (because the instrument cannot handle moisture). Because water has a molecular weight different from methane and air components nitrogen and oxygen, simply multiplying the moist flow rate times the dry methane concentration will not give an accurate methane flow rate; it will be overstated (by in the case above the 2.3% to 7.5% range referred to). The Methodology is silent on how this is to be handled.

There are other aspects of the abatement calculations that could add to the uncertainty of the calculations. These have been discussed above and include the following:

- Destruction efficiency – use of default value of 1 or 0.98 for engines and flares respectively.
- Proportion of landfill gas that is methane – use of default value of 50%.
- Oxidation factor – use of default factor of 10%.
- Electrical efficiency factor– use of default factor of 36%.
- There are some uncertainties that are inherent within the NGER (Measurement) Determination which are unavoidable, such as the methane's GWP or its calorific value.
- The measurement of non-carbon tax percentage, due to the project proponent being unable to control the data and often having to employ estimation techniques as landfills do not always keep the most consistent waste data.

Conclusion 22 The Methodology has taken reasonable steps to minimise uncertainty in measurement and data collection. Most measurement requirements are relatively straightforward and reduce uncertainty (e.g., gas flow measurements need to be within strict uncertainty limits). With the measurement of gas flow and methane concentration there is some inherent uncertainty as specified by manufacturer measurement devices. There is some uncertainty with the use of each of the default factors, particularly the default methane concentration.

3.4 Whether any reporting requirements in the method are clearly specified.

Part 5 Division 1 of the 2015 Methodology lists the information that must be included in project reports. This is reasonably clear, however, some additional guidance could be provided to project operators so that full details are included in offsets report, such as:

- compliance with different aspects of the Methodology; and
- details of the abatement calculations performed and source data to be provided/referenced.

Based on understanding obtained from projects there is limited guidance on the level of detail required in the offsets report. Therefore, it is likely that some projects will provide very detailed reports, whilst others will report on the minimum required.

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[34] The water content of the landfill gas has been estimated using a computerised simulation used by Australian universities and gas companies, with data from an ERF project, and reported in unpublished "Equations for Water Content and Properties of Gas", Prof V. Rudolph, University of Queensland, 06 May 2013.

3.4.1 2015 Methodology considerations

The offsets report requirements in the 2015 Methodology could be expanded to include specific details that are required to be assessed by the CER. Examples include project details, process flow diagrams, equipment specifications, parameters used, source data, abatement calculations, and other information as specified in the Methodology.

The current reporting requirements mean that a wide range of offsets reports are produced which is likely to increase the regulatory burden as additional information may be required by the CER if this is not clear in the offsets report. Conversely, too much information will require additional time for the verification and regulatory assessment.

An example in the 2015 Methodology where the reporting requirements are not clearly specified is the inclusion of the abatement calculations within the offsets report. For most projects, this would be intuitive to include, however the Methodology does not actually specify this within Part 5 Division 1. The limited detail included in the Methodology can create difficulties in verification, as the auditor is providing an opinion that the project report has been prepared in accordance with section 76 of the CFI Act. Section 76 (4) outlines the offsets report requirements which states that:

"An offsets report about a project for a reporting period must:

(a) be given in the manner and form prescribed by the regulations; and

(b) set out the information specified in the regulations; and [...]

(d) be accompanied by such other documents (if any) as are specified in the regulations [...]".

Conclusion 23 The 2015 Methodology reporting requirements are not clearly specified, for example it does not state that the abatement calculations, parameters, and data sources need to be included in the offsets report. It is therefore recommended that these are more clearly specified so that projects know what level of detail is required, and so there is a more standardised and common approach to reporting. Of the projects reviewed there is an apparent variability in reporting, this supports the conclusion that the reporting requirements are not clearly specified.

3.4.2 2012 Methodology considerations

The 2012 Methodology does provide more specific reporting requirements, which are summarised as follows:

Information that must be included in an offsets-report

(1) The following information is required to be included in the first offsets report for a project to which this Methodology Determination applies:

(a) carbon dioxide equivalent net abatement amount for the project;

(b) the proportion of methane generated from the landfill that is required to be captured and destroyed to meet regulatory requirements (A_{reg});

(c) justification for the proportion of methane generated from the landfill that is required to be captured and destroyed to meet regulatory requirements;

(d) if applicable, the total volume of methane sent to combustion devices, in cubic metres (sum of $Q_{sent,h}$) and total volume of methane destroyed by combustion devices, in cubic metres (sum of $Q_{com,h}$);

(e) if applicable, the quantity of methane destroyed as a consequence of an internal combustion engine, in tonnes CO_2-e ($A_{com,ice}$);

(f) total amount of fuel and/or electricity used by the project, in kilolitres (kL), cubic metres (m^3), or kilowatt hours (kWh);

(g) destruction efficiency of each combustion device (DE_h);

(h) electrical efficiency (Eff) of the internal combustion engine generator (with reference to Australian Standard AS 4594.1 or equivalent);

(i) if applicable, the date of a report required under section 19 or section 22G of the *National Greenhouse and Energy Reporting Act 2007* and the factors and parameters used in that report, as prescribed in the *NGER (Measurement) Determination* or *NGER Regulations*.

These requirements are streamlined and do not require much information to be included in the offsets report. This can lead to difficulties during verification as the offsets report is unlikely to include all the information required to demonstrate compliance with the Methodology. Nonetheless this is more detailed than within the 2015 Methodology.

Conclusion 24 There is a risk with the 2015 Methodology that, as the reporting requirements are limited, not all the information would be required to be kept under the record-keeping requirements (i.e. sections 192 and 193 of the CFI Act require records to be kept if this is used in preparing the offsets report).

If the offsets report does not specify much detail, then it is possible that the project proponent may not retain all the required information necessary to demonstrate compliance with the Methodology. This is a potential issue when it comes to the verification of methodology compliance.

3.5 Whether record keeping requirements in the method, in combination with record keeping requirements in the Act and legislative rules (which apply to all projects), would enable an auditor to verify the abatement calculations (including all inputs to calculations) and confirm that all requirements in the method have been met.

The record keeping requirements in the CFI Act, legislative rules and the methods should enable an auditor to verify the abatement calculations. Although as described above (refer to section 3.4.1), the abatement calculations are not specifically required in the 2015 Methodology offsets report. Nonetheless, there are several requirements which require a significant amount of data to be logged and retained which allows for verification. How this information is retained and presented is likely to impact the time required for verification.

For the audit of ERF projects, the auditor is required to assess overall compliance with the Methodology. Specifically, the auditor is required to provide reasonable assurance that, in all material respects:

- the proponent meets requirements of the relevant Methodology determination under subsection 106(3) of the CFI Act,
- the project report(s) has been prepared in accordance with section 76 of the CFI Act, and
- the project has been operated and implemented in accordance with the:
  - section 27 declaration,
  - relevant Methodology determination, and
  - requirements of the CFI Act.

Since the project is to be operated and implemented in accordance with the relevant CFI Methodology Determination, this requires the auditor to assess compliance with all parts and sections of the Methodology. This requires going through each part of the Methodology, assessing the relevance to the project and using the evidence retained by the project proponent to verify compliance. This is not always apparent to individual projects, and as such the CFI Methodology Determination or explanatory statements could include an additional description of the type of evidence to be retained.

Conclusion 25 Record keeping requirements in the 2015 Methodology do not include all information required to demonstrate compliance with the Methodology in full. As the auditor is verifying compliance with the whole Methodology the record keeping requirements could be specified in additional detail to assist with the verification process.

The record-keeping requirements in the Act are defined as follows:

In section 192 - Record-keeping requirements—preparation of offsets report

Scope

(1) This section applies if a person:

(a) made a record of particular information; and

(b) used the information to prepare an offsets report.

Record-keeping requirements

(2) The regulations may require the person to retain:

(a) the record; or

(b) a copy of the record;

for 7 years after the offsets report was given to the Administrator.

In section 193 - Record-keeping requirements—methodology determinations

Scope

(1) This section applies if:

(a) a person is the project proponent for an eligible offsets project; and

(b) under the applicable methodology determination, the person is subject to a record- keeping requirement relating to the project.

Sections 192 and 193 can be interpreted as any information recorded that is used in preparing the offsets report should be retained. As such, it is important that the information to be included in the offsets report is clearly defined within the CFI Methodology Determination. Otherwise, there is a risk that when it comes to verification not all the required information to assess compliance with the Methodology is available. Examples within the landfill gas Methodology include:

- the historical waste data from the landfills (used to determine legacy waste and non-carbon tax proportions), and
- evidence supporting the determining of baseline abatement.

In determining the baseline abatement, the auditor would require access to relevant information such as landfill licenses, environmental permits, local authority and State regulations, etc. Whilst this type of information should be readily available at the landfill, if the requirement is not specifically noted, this may lead to difficulties during verification.

3.5.1 Calculation requirements

The offsets report should present the calculated abatement. Additionally, all supporting information is expected to be retained and either included in the offsets report or referenced. For example, all relevant parameters and equations should be clearly justified and any measured or monitored data recorded for verification. The calculations and monitored parameters are clearly defined in the Methodology and under sections 191 to 194 of the CFI Act, the project proponent must comply with the monitoring requirements.

Record-keeping requirements outlined in the 2012 Methodology under section 4.4 are very detailed, and require records to be kept for general information, combustion device information, monitoring device information, data required on the direct and indirect measurement, and legacy waste proportion data. This in combination with the detail specified in the offsets report requirements means that the 2012 Methodology should allow the auditor to verify the abatement calculations and confirm that all requirements in the Methodology have been met.

Conclusion 26 Record-keeping requirements, as defined in the CFI Act, require project proponents to retain records if they are used in the preparation of the offsets report. There are some gaps in the specific detail to be included in offsets reports that could lead to required information not being recorded. Furthermore, if the reporting and record-keeping requirements do not cover all aspects of the Methodology, then it could be difficult for an auditor to verify that all requirements in the Methodology have been met.

Conclusion 27 In the 2015 Methodology, the abatement calculations should be verifiable (i.e. the project must provide the required data to support each parameter and assumption used in the equations). However, the record keeping requirements (when compared to the 2012 Methodology) are very limited in detail and do not explicitly specify the records that must be kept. In contrast, section 4.4 of the 2012 Methodology is very specific in the record keeping requirements. As such, the 2012 Methodology is more straightforward to verify than the 2015 Methodology.

3.6 Whether record keeping requirements in the method provide sufficient flexibility to accommodate different types of evidence available to proponents

As described in section 3.5 of this report, record keeping requirements in the 2015 Methodology are not clearly defined. However, the different types of evidence available to proponents are limited for most data requirements. This means that whilst there is some flexibility to proponents in the evidence required, for many of the required parameters, the source data is likely to only be in one format (e.g. gas flow data, methane concentration, electricity generation, etc.).

Similarly, for compliance with aspects of the Methodology such as the calculations and baseline assessment, the project proponent will be required to justify the assumptions and data used. This information needs to be provided to the auditor for verification.

There are limited aspects to this Methodology where flexibility in the evidence provided is available. This is presumably one reason why the record keeping requirements are not overly specific - the calculation requirements cover most of the evidence that is required.

As the 2015 Methodology is not specific about the different types of evidence that can be used, the project proponent may use different types of evidence available, for example:

- *supporting justification for the baseline assessment*; there may be more than one source of information used to justify the baseline, depending on whether the project is a transitioning, upgrade or new project, and, if it is a new project, the source of the estimate for the regulatory proportion. Furthermore, evidence related to the option chosen - essentially including all documents relied upon - will need to be supplied. The options, as specified in Schedule 1 of the Methodology are:
  - Reference to State or Territory guidelines for landfilling.
  - Asking the environmental regulator what gas capture rate is needed to comply.
  - Asking the environmental regulator whether the current gas capture rate is compliant.
  - Determined by an independent expert.
- *historical landfill waste composition data*; different landfills are likely to have different systems and processes for recording waste received; and
- *non-monitored data*; the proponent might be able to utilise different types of evidence to support assumptions when equipment or instruments fail.

In contrast, the 2012 Methodology's record-keeping requirements (section 4.4) are quite specific, and could reduce the flexibility in the types of evidence available. Nonetheless, the 2012 Methodology enables a more straightforward audit process (i.e. verification).

<u>Conclusion 28</u> There are differences between the 2012 and 2015 Methodologies regarding the record keeping requirements. The 2012 Methodology has relatively detailed and specific record keeping requirements which potentially reduce the flexibility in the type of evidence available to proponents. However, this is likely to make the verification process more straightforward. Contrastingly, the 2015 Methodology has limited record-keeping requirements, which increases the flexibility in evidence requirements, but can potentially create more issues in the verification process.

<u>Conclusion 29</u> There are not many aspects of the CFI Methodology Determination where the type of evidence has much flexibility, i.e., equipment and instrument data obtained from the monitored parameters is likely to only be derived from one source. Hence, whilst there could be some flexibility, the methods are prescriptive in the data that is required for the abatement calculations.

4 Assessment of whether the method is supported by clear and convincing evidence

<u>*Summary:*</u>

This section explores whether the landfill Methodology is supported by clear and convincing evidence. This was done via a detailed assessment of the Methodology and supporting relevant information sources (e.g. NGER Measurement Determination, CDM, etc.) and relevant literature in the subject.

4.1 Whether there is clear and convincing evidence to support

Clear and convincing evidence can be defined as being supported by relevant scientific results published in peer-reviewed literature (see paragraph 133(1)(d) of the Act). The response to this requirement therefore focuses on the available literature that is relevant to addressing each sub-requirement.

This section considers the following requirements:

- The scope of activities and circumstances covered by the method, section 4.1.1;
- The calculation approaches used, section 4.1.2;
- The appropriateness, accuracy and scientific validity of monitoring, measurement and data collection requirements, section 4.1.3;
- The inclusion and exclusion of emissions sources that are a direct consequence of the project including on the grounds of materiality, section 4.1.4; and
- The appropriateness and conservativeness of all estimates, assumptions, and projections, section 4.1.5.

4.1.1 The scope of activities and circumstances covered by the method

In both, the 2015 and 2012 Methodologies, the scope of the activity and circumstances covered by the landfill gas Methodology is landfill gas that is destroyed over and above regulatory requirements that are eligible for ACCUs. The clearest evidence to support ACCUs being issued for additional landfill gas abatement is the continued use and support of the CDM landfill gas Methodology.

The United Nations Framework Convention on Climate Change (UNFCCC) supports landfill gas abatement as being eligible for carbon credits and is now operating under version 18.0[35]. The Methodology mirrors the CDM methodology in most regards, with additional regulatory baseline determinations tailored to the Australian regulatory environment. Whilst the CDM continues to support landfill gas destruction, there is clear and convincing evidence that the ERF landfill gas methodology scope and circumstances are supported.

[35] UNFCC, (2017) Flaring or use of landfill gas v18.0, 4 May 2017. Accessed on 16/08/17, available from: https://cdm.unfccc.int/UserManagement/FileStorage/0X2IE6B1PJDLKMWN89AZGTFUHR3VYS.

Conversely to the CDM, the Landfill Directive in the European Commission (EC) places strict requirements on the collection of landfill gas[36]. Annex I of the EC Landfill Directive defines the requirements for gas control as provided below:

> *4. Gas control*
>
> *4.1 Appropriate measures shall be taken in order to control the accumulation and migration of landfill gas (Annex III).*
>
> *4.2 Landfill gas shall be collected from all landfills receiving biodegradable waste and the landfill gas must be treated and used. If the gas collected cannot be used to produce energy, it must be flared.*
>
> *4.3 The collection, treatment and use of landfill gas under paragraph 4.2 shall be carried on in a manner which minimises damage to or deterioration of the environment and risk to human health.*

In essence, the Landfill Directive states that landfill operators must maximise the amount of landfill gas that they collect[37]. In Europe, landfill operators are required to recover the maximum amount of energy from the landfill gas over the whole lifecycle of the landfill. It is noted that the best available techniques should be applied. The following utilisation techniques have been applied successfully:

- Introduction of the treated methane into the gas mains.
- Combined heat and power utilisation.
- Direct use of the gas as a fuel.
- Electricity generation.

If it is not possible or economically infeasible to generate energy, then landfill operators in Europe are required to flare the gas. In many European member States, this has been common practice for over two decades, and it therefore could be argued that landfill gas capture is common practice in many developed countries. As such, in Europe, the additionality of landfill gas flaring could be questioned.

There are slight differences between the 2012 and the 2015 Methodologies that impact the scope of activities covered. These differences are highlighted in the below sections.

4.1.1.1 2015 Methodology considerations

Under the 2015 Methodology, the scope of activities and circumstances covered is restricted to projects that reduce GHG emissions by collecting and combusting landfill gas. A landfill gas project may be:

a) a new project (section 9 of the Methodology); or

b) a recommencing project (section 10 of the Methodology); or

c) an upgrade project (section 11 of the Methodology); or

d) a transitioning project (section 12 of the Methodology).

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[36] EC, (2013) Landfill Gas Control -Guidance on the landfill gas control requirements of the Landfill Directive. Accessed on 16 August 2017 from: http://ec.europa.eu/environment/waste/landfill/pdf/guidance%20on%20landfill%20gas.pdf

[37] EC, (1999) Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste. European Commission (EC). Accessed on 16 August 17, from: http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31999L0031

Each of the project requirements defined in Part 3 of the Methodology clearly defines the scope of activities and circumstances for a project to generate ACCUs. All projects must collect landfill gas through a landfill gas collection system at a landfill and combust the gas using a combustion device.

4.1.1.2 2012 Methodology considerations

The scope of activities and circumstances covered by the 2012 Methodology (section 1.3) includes the following types of landfill legacy emissions avoidance projects:

a) transitioning Greenhouse Friendly projects;

b) transitioning GGAS projects; and

c) projects that involve the following activities:

   (i) installing, on or after 1 July 2010, a landfill gas extraction system; and

   (ii) collecting gas emitted from legacy waste from the landfill facility; and

   (iii) combusting the methane component of the gas using a combustion device to chemically convert it to carbon dioxide (CO_2).

In the application of the 2012 Methodology 'installing a landfill gas extraction system' does not include the reinstallation, or replacement of, upgrades to, or modifications of an existing system, where such systems were installed prior to 1 July 2010 (refer to Figure 7 for a graph of project volumes by year.) A project under the landfill gas 2012 Methodology that is not a transitioning project must include the installation of a new system, in entirety, where no system has previously been installed.

Part 2 of the 2012 Methodology further defines the requirements that must be met for an offsets project to be eligible. In addition to the above defined landfill legacy emissions avoidance projects, the projects must relate to the capture and combustion of emissions from legacy waste only (i.e. credits are not issued for solid waste containing biodegradable organic matter accepted by a landfill facility after 1 July 2012). Furthermore, the proportion of methane that is required to be captured or destroyed to meet regulatory requirements must be calculated in accordance with the relevant guidelines (refer to section 2.4.1.2) or specific landfill licence requirements (refer to section 2.4.1.3) for calculating regulatory baselines. The scope of activities and circumstances covered by the 2012 Methodology is therefore restricted.

4.1.1.2.1 Transitioning Greenhouse Friendly and GGAS projects

Greenhouse Friendly was the program administered by the Commonwealth Government. GGAS was the New South Wales Government's Greenhouse Gas Reduction Scheme and the Australian Capital Territory Government's Greenhouse Gas Abatement Scheme. Both Greenhouse Friendly and GGAS projects were included in the Department of Environment's *Positive List* contained in the Carbon Credits (Carbon Farming Initiative) Regulations 2011. This means the activity is an emissions avoidance activity and such projects are not subject to permanence obligations. The Australian Government reviews the *Positive List* periodically with a view to keeping the list current considering technological developments and the latest scientific research.

4.1.1.2.2 New projects

A new project is required to:

- install, on or after 1 July 2010, a landfill gas extraction system; and
- collect gas emitted from legacy waste from the landfill facility; and
- combust the methane component of the gas using a combustion device to chemically convert it to carbon dioxide (CO_2).

There is peer-reviewed literature that demonstrates the combustion of landfill gas will reduce GHG emissions through the conversion of methane (CH_4) to carbon dioxide (CO_2), in consideration of each gas' GWP. If a landfill has no regulatory requirement to collect and combust methane, then this provides a basis for defining the scope of activities that allow projects to generate ACCUs.

4.1.2 The calculation approaches used

The calculations employed in the Methodology follow the same general format of the CDM Methodology, but are adjusted for the Australian regulatory and measurement environment. Landfill gas project methodologies under the CDM were first published in 2004, and the approach is well tested and widely adopted[38].

Calculations in the Methodology do differ from the CDM methodology, as the scope of the former is more limited than the latter (such as not allowing for emission reductions for displaced fossil fuel generated electricity from the grid). In addition, the Methodology needs to accommodate NGER requirements such as the non-carbon tax waste percentage, which the CDM methodology does not consider. However, the combination of the similar calculations of the CDM methodology adjusted for NGER and the Australian regulatory environment do provide clear and convincing evidence for the support of the calculations used.

Section 3.1 describes the calculations for both the 2015 and 2012 Methodologies. The calculation approaches under both Methodologies follow robust scientific approaches with additional regulatory baseline assessment being underpinned by Federal and State Government legislation (refer to section 4.2).

4.1.2.1 2015 Methodology considerations

The calculations in the 2015 Methodology are underpinned by peer-reviewed scientific literature. For example, the NGER (Measurement) Determination sections that are referred to in the Methodology are all based on a rigorous scientific method that follows national and international standards for measurement of greenhouse gases. The origins and source references used are not well documented within the Determination itself. However, these should be well known by the DoEE and are comparable to methodology approaches used in other jurisdictions.

The deduction of baseline abatement from project abatement is underpinned by the CDM and the additionality test required under the CFI Act.

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[38] UNFCCC, (2004) Flaring or use of landfill gas v1.0, 2 Sept 2017. Accessed on 16/08/17 and available from: https://cdm.unfccc.int/UserManagement/FileStorage/eb15repan1.pdf

4.1.2.2 2012 Methodology considerations

The calculations in the 2012 Methodology follow peer-reviewed scientific literature. Emissions from the project and regulatory requirements are deducted from the emissions avoided as a consequence of the project (refer to section 4.1.4).

4.1.3 The appropriateness, accuracy and scientific validity of monitoring, measurement and data collection requirements

The monitoring, measurement and data collection requirements in the 2015 and 2012 Methodologies are similar. Both methods require certain parameters to be monitored and measured. The most important (i.e. material) parameters are summarised and assessed in Table 14. In general, the monitored and measured data collected is considered appropriate. The data collected and used in the abatement calculations follow a scientific approach and is sufficient to calculate ACCUs. It is understood that the development of the NGER (Measurement) Determination has gone through a robust scientific peer review process.

Most of the parameters outlined in Table 14 are underpinned by clear and convincing evidence (i.e. the measurements follow widely adopted national and international calculation methods commonly used in industry). For example, the CDM requires similar approaches for measurement, monitoring and data collection.

The measurement of mass flow of a GHG in a gaseous stream is underpinned by the CDM's methodological tool that is based on the fundamentals of thermodynamics[39] and drying[40]. Unlike most commercial gas streams in pipelines (such as natural gas and compressed air), landfill gas contains moisture, estimated for one ERF project as ranging on a 95% confidence interval from 2.3% (gas at 23°C in winter) to 7.5% (gas at 38°C in summer) on a molar (and therefore approximately on a volume) basis[41]. Flow measurement is usually done on the moist gas, but concentration measurement using a gas chromatograph is done on dried gas (because the instrument cannot handle moisture). Because water has a molecular weight different from methane and air components such as nitrogen and oxygen, multiplying the moist flow rate times the dry methane concentration will not give an accurate methane flow rate; it will be overstated by, in the case above, the 2.3% to 7.5% range referred to. The Methodology is silent on how this is to be handled.

Compliance with requirements for monitoring of parameters is important as this underpins the correct calculation of abatement credited by the project. Monitoring requirements (section 33 of the 2015 Methodology) include the process for monitoring and the standard to which monitoring must occur. In some cases, a project may be unable to monitor a parameter to the requirements specified. When this occurs, section 34 of the 2015 Methodology requires that adjustments be applied for the time intervals that the parameters are not being monitored in accordance with requirements (termed the non-monitored period). The adjustment is necessary to ensure that all estimates or assumptions

[39] Van Wylen, G.J., Sonntag, R.E. and Borgnakke, C. (1994), Fundamentals of Classical Thermodynamics, Fourth Edition, John Wiley & Sons, Inc.
[40] Strumillo, C. and Kudra, T. (1986), Drying: Principles, Applications and Design, Gordon & Breach Science Publisher; Montreaux, Switzerland.
[41] Rudolph, V. (2013), The water content of the landfill gas has been estimated using a computerised simulation used by Australian universities and gas companies, with data from an ERF project, and reported in unpublished "Equations for Water Content and Properties of Gas", University of Queensland, 06 May 2013.

used in the Methodology are conservative and are in accordance with the offsets integrity standards outlined in section 133 of the CFI Act.

The main exceptions to potential deviations from scientific validity are where the use of default factors is allowable. As such, the use of default factors may cause uncertainty and may not always be conservative, and therefore appropriate. Further description of these parameters is provided in the following sub-sections.

Table 14: Key parameters required to be measured and monitored

Description	Unit	Parameter		Measurement method
		2012	2015	
Quantity of landfill gas sent to a combustion device (h)	m^3	$Q_{sent,h}$	$Q_{LFG,h}$	Continuously measured by a flow meter, corrected to standard conditions. Section 3.15 of the 2012 Methodology provides the requirements for volumetric measurement. Same approach as described in the 2015 Methodology and defined in Division 2.3.6 of the NGER (Measurement) Determination using measurement criteria AAA.
Methane destruction efficiency for device h	%	DE_h	DE	DE can be measured (but not required) in the 2012 Methodology by a National Association of Testing Authorities (NATA) accredited emission stack testing company, using a method based on US EPA Method 18. However, the 2015 Methodology requires the use of default values.
Methane fraction in the landfill gas	m^3CH_4 / m^3 landfill gas	W_{CH4}	$W_{LFG,CH4}$	Under the 2012 Methodology, measured in accordance with section 3.15. Under the 2015 Methodology, estimated under Division 2.3.6 of the NGER (Measurement) Determination. Alternatively, the default value of 0.5 from section 5.14 (c) of the NGER (Measurement) Determination can be used in each method.
Quantity of electricity used for abatement activity	kWh	Q_{elec}	N/A	Measured using the relevant meter and sub-meter or estimated from the invoiced amount of electricity supplied to the landfill.
Quantity of fuel used for abatement activity	kl or m^3	Qi	N/A	For each fuel used the amount must be estimated (from meter or invoice) as a proportion of totals for the facility.
Quantity of electricity produced by methane combustion in internal combustion engine generator (h)	MWh	E_{Ph}	$Q_{EG,h}$	Meter data equivalent to a revenue meter must be used (highly accurate).
Electrical efficiency factor of the internal combustion engine generator	%	Eff	Eff_h	Uses the manufacturer specification or can use 0.36 default value derived from 2.38(2)(a)(ii) of the NGER (Measurement) Determination.

Description	Unit	Parameter		Measurement method
		2012	2015	
Energy content of the landfill gas sent to combustion device h	GJ	E_{lfg}	$Q_{En,h}$	The 2012 Methodology requires the use of flow computer and Schedule 1, Part 2 of the NGER (Measurement) Determination. In the 2015 Methodology, estimated under Division 2.3.6 or section 6.5 (using measurement criteria AAA) of the NGER (Measurement) Determination.

4.1.3.1 Methane destruction efficiency (DE)

The default methane destruction efficiency for a combustion device of 0.98 in the 2015 Methodology is based on the use of an enclosed flare. This is the most usual arrangement for safety and control reasons.

The 2012 Methodology also allows the use of 0.98 but does give the option to measure the methane destruction efficiency. It is therefore likely that projects will select the most beneficial value in terms of total ACCUs. Consequently, allowing the option to measure (or use default value for DE) may not always be conservative or appropriate (i.e. the proponent would most likely select the default value if it was more beneficial to ACCUs generated).

The default methane DE for an internal combustion engine device in the 2015 Methodology is 1.00. This appears reasonable for large internal combustion engines such as electricity generators. Nonetheless, consideration should be given to research performed in Germany on uncombusted methane from internal combustion engines that shows all engines have some methane slip which can vary at different scales, see Figure 10.

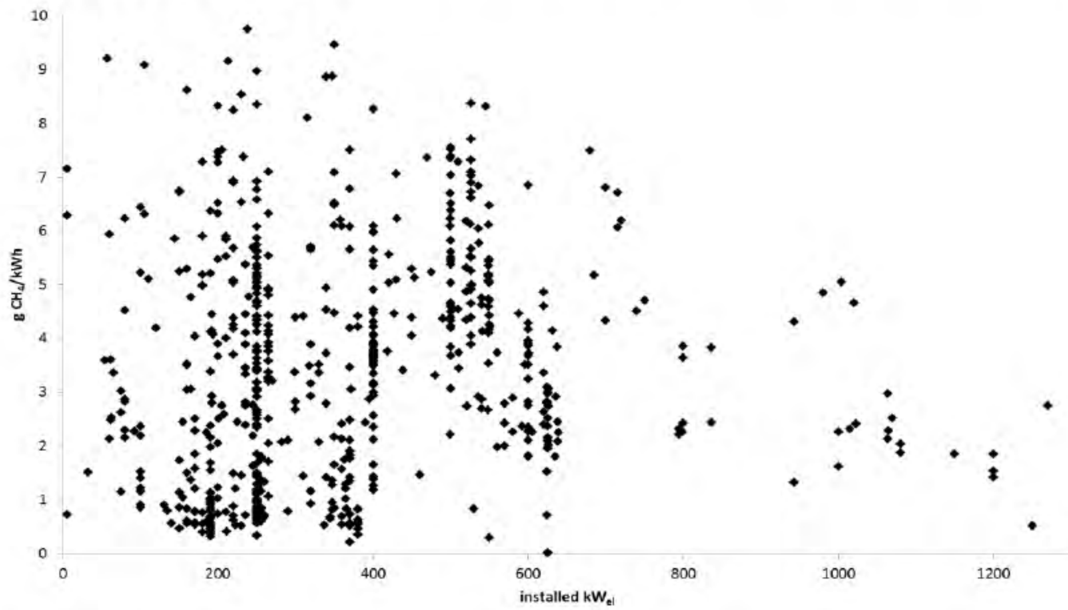

Figure 10: Uncombusted methane emissions from biogas engines in Germany (Clemens et al, 2014)[42]

[42] A review of methane loss in engines from combustion of biogas in Germany, in Clemens et al, (2014). The diagram is taken from the presentation "Experiences from Emission Analysis as a Tool for Plant Optimization", held by Dr Joachim Clemens, bioanalytic GmbH, Troisdorf at the IBBA Methane emission workshop in Kiel, Germany on 4 September 2014.

4.1.3.2 Methane fraction in the landfill gas

The default methane percentage is set at 50% which is the same as the CDM. The reference for the 50% values appears to be derived from Intergovernmental Panel on Climate Change (IPCC) 2006 guidelines for national greenhouse gas inventories. This represents a reasonable and potentially conservative average estimate. Nevertheless, it is possible to operate a flare with methane concentrations lower than 40%. Low methane concentrations can occur, particularly towards the end of the methane generation cycle from a waste body.

Gas composition analysers are widely used in landfill gas collection systems and may be used in ERF projects, but are not compulsory. As mentioned in section 2.2.1.1, once a project has used measurement, it must continue to do so under section 24(3) of the 2015 Methodology. However, if the project commences using the default value it can continue to be used indefinitely. Projects still using the 2012 Methodology can change to and from the default factor as they wish.

The use of default values for methane concentration may therefore not always be supported by clear and convincing evidence. A key risk is that air may be added to the landfill gas collection system which would increase the flow of landfill gas whilst reducing the methane concentration. As such, projects would benefit from using the default value of 50%.

There are projects that are known to not measure the gas composition. This can be done either on a continuous basis or a periodic sample basis using hand held gas analysers or bag samples. Nonetheless, the Methodology does not stipulate that this data is required to be used which could lead to an over estimation of calculated abatement. From a reasonable assurance perspective, it would be questionable why you would measure methane concentration as less than 50% but then use the default value of 50%.

4.1.3.3 Electrical efficiency of the internal combustion engine

Under both the 2012 and 2015 Methodologies, it is allowable to use the default electrical engine efficiency of 36% which is a commonly used value. All engines would be expected to have a technical specification. Even though the variability of the landfill gas composition will dictate this efficiency, (i.e. the composition of landfill gas will vary in amounts of methane and carbon dioxide which may mean the manufacturer specification cannot always be accurately used).

The gas composition can vary with different methane concentrations and trace gases likely to affect the electrical efficiency of the internal combustion engine. Off-grid engine and gas turbine systems have different default efficiencies depending on the nominal capacity of the power generation unit. An example from the CDM is provided in Table 15.

Table 15: Default efficiency for off-grid power plants[43]

Location	Nominal capacity of power plants (CAP, in kW)						
Generation Technology	CAP≤10	10≤CAP≤50	50≤CAP≤100	100≤CAP≤200	200≤CAP≤400	400≤CAP≤1,000	CAP>1,000
Reciprocal engine system (e.g. diesel, fuel oil, gas engines)	28%	33%	35%	37%	39%	42%	45%
Gas turbine systems	28%	32%	34%	35%	37%	40%	42%

This shows that the electrical efficiency increases with the engine capacity. It also demonstrates the expected variation in efficiency. Since all engines should have a technical specification it would be anticipated that should be used. The impact of the engine efficiency assumption is assessed in section 5.

4.1.4 The inclusion and exclusion of emissions sources that are a direct consequence of the project including on the grounds of materiality

Activities that must be accounted for abatement calculations in the 2012 Methodology are shown in Figure 11 and include:

- grid-derived electricity and/or fuel used in the process of gas capture and combustion. For example, the electricity and fuel used to power pumps and engines used in the operation of flares, as well as in the operation of control and monitoring systems;
- supplemental fuel, for example; natural gas, if used to sustain combustion of landfill gas in a flare or combustion engine. Where emissions are generated by the combustion process, and fugitive emissions from the incomplete combustion of the methane and the generation of nitrous oxide during the combustion process;
- landfill gas that is captured and destroyed by an internal combustion engine to generate electricity; and
- landfill gas that is captured and destroyed via an open or enclosed flare.

[43] UNFCC, (2017) Flaring or use of landfill gas v18.0, 4 May 2017. Accessed on 16/08/17, available from: https://cdm.unfccc.int/UserManagement/FileStorage/0X2IE6B1PJDLKMWN89AZGTFUHR3VYS

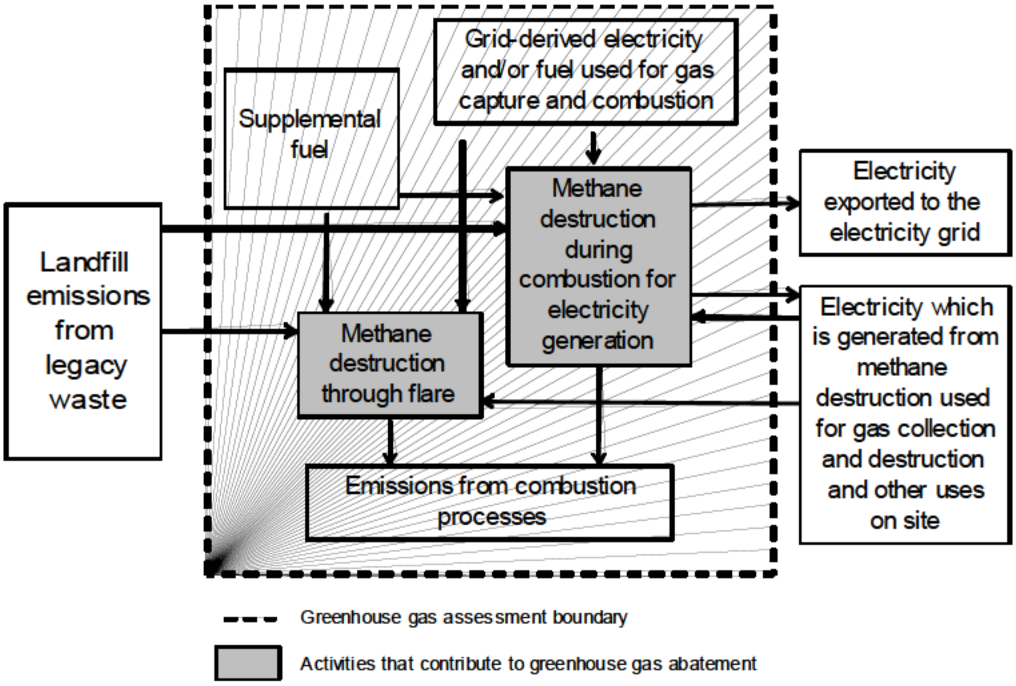

Figure 11: Flow diagram - GHG assessment boundary for an abatement activity (2012 Methodology)[44]

The GHG assessment boundary does not include the GHG emissions from landfill waste, as it is not required for the purpose of calculating the abatement from the methane captured and destroyed. However, an estimate of the emissions from the landfill waste is required for the purpose of calculating the proportion of methane generated from legacy waste (and for the carbon tax fraction in the 2015 Methodology).

The 2012 Methodology includes project emissions from electricity and fuel use. Based on projects we have obtained information on, it is understood that these emissions are not expected to be material in relation to the total calculated abatement. A high level check of the projects would show that electricity and fuel use are likely to be moderate in relation to the total flow of landfill gas and methane. Moreover, as methane has a higher GWP than carbon dioxide. it is apparent that emissions from fuel combustion would have to be significant to materially impact the calculated abatement.

The 2015 Methodology does not include the GHG emissions from electricity and fuel use which demonstrates that these emissions can be excluded from the project boundary to simplify the method.

Emissions from combustion of the landfill gas (e.g. N_2O and CH_4) have been excluded from the 2015 Methodology (previously included in the 2012 Methodology) presumably on the basis that they do not have a material impact on the total calculated abatement, which is reasonable.

[44] Clean Energy Regulator (undated), "Participating in the Emissions Reduction Fund: A guide to the capture and combustion of methane in landfill gas from legacy waste method" (2012 Methodology).

Additional potential emission sources include:

- Electricity: monitoring and measurement equipment is expected to use electricity. Nevertheless, GHG emissions from electricity use would not be material (<1%) in relation to the total methane flows.
- Start-up fuel: flares and internal combustion engines may require start-up fuel (e.g. diesel, LPG or natural gas). Nonetheless, a very small amount of fuel would be used before switching to landfill gas.

The inclusion and exclusion of major sources follows a similar format to the CDM methodology. It is therefore deemed appropriate. The materiality threshold has led to the removal of some smaller emission sources from the calculation. For example, the emission of nitrous oxide (N_2O) during the combustion of landfill gas has been removed from the abatement calculation under the ERF which is conservative. It is noted the materially threshold was employed to simplify the ERF landfill gas in the 2015 Methodology compared to the 2012 Methodology. Given the removal of emission sources such as nitrous oxide are less than 1% of the emissions stemming from the project, it is considered appropriate given the materiality threshold employed.

The GHG emissions assessment boundary does not include reductions in carbon dioxide emissions caused by displacing electricity derived from fossil fuel. This is not an eligible source of abatement for crediting under the ERF. This is considered a valid approach since it would require a consequential modelling approach which would not been appropriate at the individual project level[45]. Furthermore, the electricity generation component is covered by the RET.

GHG emissions from electricity used for gas capture and combustion are not included in the GHG emissions assessment boundary where that electricity is created using methane and combusted on-site. This is because the emissions from the combustion process are already included in the GHG emissions assessment boundary.

Carbon dioxide emissions associated with the generation and combustion of landfill gas are biogenic. This means that, biological capture balances over a sufficiently short time, such that release of carbon dioxide can be considered to have no net impact on atmospheric GHG levels. Thus, these emissions are not included in the GHG emissions assessment boundary which is common practice in GHG emissions accounting.

4.1.5 The appropriateness and conservativeness of all estimates, assumptions, and projections

4.1.5.1 Monitoring parameters

Compliance with requirements for monitoring of parameters is important to ensure that abatement credited by the project is calculated correctly. Monitoring requirements (refer to Table 14) include the process for monitoring and outline the standard to which monitoring must occur.

In some cases, a project may be unable to monitor a parameter to the requirements specified. When this occurs, section 34 of the Methodology requires that adjustments be applied for the time

[45] Plevin, R., Delucchi, M. & Creutzig, F. (2013) "Using attributional Life Cycle Assessment to estimate climate-change mitigation benefits misleads policy makers, J. Ind. Ecol., 18 (1), 73-83.

intervals that the parameters are not being monitored in accordance with requirements (termed *the non-monitored period*). The adjustment is necessary to ensure that all estimates or assumptions used in the Methodology are conservative and in accordance with the offsets integrity standards outlined in section 133 of the CFI Act.

For parameters listed in item 1 of the table in subsection 34(1) of the Methodology (i.e. $W_{LFG,CH4}$), the consequence for not monitoring in accordance with the requirements is to use the default emissions factor for that parameter. This is considered conservative as is included in the lower order monitoring option for the parameter. Furthermore, the proponent need to apply a 10 per cent adjustment to the default emissions factor (i.e. the factor is multiplied by 0.9) for a period of up to three (3) months in any 12-month period. For any period in excess of these three (3) months, then the adjustment is 50 per cent (i.e. the factor is multiplied by 0.5).

For parameters listed in item 2 of the table, (i.e. $Q_{En,h}$, $Q_{LFG,h}$ and $Q_{EG,h}$) the consequence for not monitoring these parameters in accordance with the monitoring requirements is for the proponent to make a conservative estimate of the parameter for the duration of the non-monitored period.

The need for a proponent to apply section 34 arises from failure to meet monitoring requirements. When section 34 is used, the project will be required to include information relating to the monitoring failure in its offsets report for the relevant reporting period (set out in section 31). This is to provide the CER with evidence that will allow them to determine the nature, and frequency, of the failure to meet the monitoring requirements of the Methodology. The approach taken for non-monitored periods should be conservative otherwise ACCUs will not be issued which is appropriate.

4.1.5.2 Baseline determination

As depicted in section 2.2.4, the baseline determination is one of the main estimates and assumptions included in the abatement calculations. This is determined following legislative and regulatory published information. However, it is not apparent that this is based on clear and convincing peer-reviewed scientific evidence. Different landfill gas projects may receive different baselines. The baseline applied to a project is the main factor when assessing the risk of under- or over-crediting. If a baseline is too high, a project would not be credited ACCUs for abatement additional to regulatory requirements, and may mean the project does not go ahead. By contrast, if a baseline is too low, a project will receive ACCUs for abatement that would have occurred regardless because of regulatory requirements. This is further assessed in section 4.2.

4.1.5.3 Landfill gas calculator

Refer to section 2.5.2 for a discussion on the landfill gas calculator and its use in the exclusion of emissions from waste deposited during the carbon tax period. Modelling emissions from solid waste deposited at a landfill as several uncertainties, however the use of the NGER landfill emissions calculator is required and therefore is appropriate. There is no evidence to suggest that this calculator is not conservative.

4.1.5.4 Methane oxidation factor

As landfill gas passes through the landfill cover or cap, methanotrophic bacteria oxidise some of the methane. The extent of oxidation varies with the type and thickness of cover material, moisture levels, temperature and the gas flux rate[46,47,48]. The IPCC (2006) guidelines sets a default value of zero for national greenhouse gas inventories but indicates that a value of 10% may be appropriate where landfills are well managed. The Australian national inventory uses the 10% value and requires this in NGERS reporting. All but one of the reviewed life cycle assessments (LCAs) put oxidation factors to 10%.

Methane oxidation rates can be estimated in laboratory experiments and *in situ* through carbon isotopes measurements in gases below and above the cap. This work shows that oxidation greater than 10% are readily possible. A literature review[49] concludes that up to 30% could be expected. Another, more recent literature review[50] of 42 studies found a mean oxidation factor value of 36% and only four reporting values of 10% or less. In clayey soil covers the average oxidation factor was 18%. The field studies, on average, had a lower oxidation factor than the laboratory studies, probably because "cracks and fissures … in the field allow some CH_4 to bypass oxidation[51]".

4.1.5.5 Non-carbon tax percentage

Emissions of landfill gas start a year after waste deposit and continue for occur over a long period, based on the model set by the NGER (Measurement) Determination. For example, based on this Methodology, a Victorian landfill that accepted an equal quantity of waste during the carbon tax years, only 2.3% of the emissions would have arisen during those years.

There does not appear to be sufficient and appropriate peer-reviewed scientific evidence to support the inclusion of the non-carbon tax percentage estimation, however the calculations used in the landfill gas model are considered to be appropriate.

Where landfills report under NGER, this calculation is not overly difficult, as the required information is already collected and collated, and such landfills are familiar with the solid waste calculator. For smaller sites that do not report under NGER, however, the data requirements are onerous.

4.1.5.6 Historical waste data

The project participant must report annual tonnages, and the proportional split across waste type, since the landfill opened. The project proponent does not generally have access to this historical data, and it is often incomplete, based on low quality estimates, and difficult to compile to a standard acceptable to auditors.

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[46] Streese, J. and Stegman, R., (2003) Design of biofilters for methane oxidation. In Proceedings of Sardinia.
[47] Gómez, K.E., Gonzalez-Gil, G., Lazzaro, A. and Schroth, M.H., (2009) Quantifying methane oxidation in a landfill-cover soil by gas push–pull tests. Waste Management, 29(9), pp.2518-2526.
[48] Schuetz, C., Bogner, J., Chanton, J., Blake, D., Morcet, M. and Kjeldsen, P., (2003) Comparative oxidation and net emissions of methane and selected non-methane organic compounds in landfill cover soils. Environmental science & technology, 37(22), pp.5150-5158.
[49] Jensen, J.E.F. and Pipatti, R., (2002) CH_4 emissions from solid waste disposal, background paper on good practice guidance and uncertainty management in national greenhouse gas inventories.
[50] Chanton, J.P., Powelson, D.K. and Green, R.B., (2009) Methane oxidation in landfill cover soils, is a 10% default value reasonable?. Journal of Environmental Quality, 38(2), pp.654-663.
[51] Ibid. p.658.

When considering the question of the conservativeness of assumptions used in the calculation of the non-carbon tax percentage this is difficult to assess as it applies the same modelling to both carbon tax and non-carbon tax years. This produces a fraction that is applied to the calculated abatement. Overall, the removal of the carbon tax fraction can be considered conservative.

4.1.5.7 Other estimations, assumptions and projections

Other estimations and assumptions included in the Methodology have been discussed previously and include:

- methane concentration (sections 2.2.1.1 and 3.2.1.1),
- methane destruction efficiency (sections 2.2.1.4 and 3.2.2),
- electrical efficiency (section 3.2.2), and
- oxidation factor (section 3.2.3.3).

The effect of the conservativeness and appropriateness of these parameters is further assessed in Section 5.

Conclusion 30 There are no apparent projections used under the landfill gas Methodology as it is reliant on direct measurement and calculations. When compared to other CFI/ERF methods (other than previously discussed estimations/assumptions) the landfill gas Methodology is considered to use appropriate and conservative values. Furthermore, wherever practical, these are aligned with NGER (Measurement) Determination methods which also compare to other international methods such as those adopted by the CDM.

4.2 Whether the 30 per cent default regulatory proportion defined in section 28 of the method is supported by clear and convincing evidence. The conclusion should be supported with reference to state and territory requirements for landfill gas capture.

Refer to section 2.2.4.2 for background information. Section 28 of the Methodology refers to the proportion of methane that would have been combusted without the project. It is divided into:

- New or recommencing project
- Upgrade project
- Transitioning projects

Each of these project types includes reference to the regulatory proportion:

- *$W_{B,Reg}$ means the regulatory proportion of the methane combusted during the reporting period that would have been combusted without the project as determined using Schedule 1 to this determination.*

Under the 2015 Methodology, the regulatory proportion is calculated with reference to Schedule 1 of the Methodology, which provides four options:

1. Reference to State or Territory guidelines for landfilling.
2. Asking the environmental regulator what gas capture rate is needed to comply.
3. Asking the environmental regulator whether the current gas capture rate is compliant.
4. Determined by an independent expert.

4.2.1.1 Option 1: Reference to State or Territory guidelines for landfilling

The State or Territory guidelines for landfilling are interpreted as setting limits for gas concentrations above the landfill. These levels are linked to a percentage gas capture rate through modelling. The modelling links methane generation (calculated using NGER methods) to concentrations above the landfill, using a model. The model is based on landfill surface area and the proportions of the surface area under different types of cover.

The authors of this report have not been able to assess all the source of information for this option (i.e. a transparent version of the CFI landfill methane regulatory baseline calculation). Nevertheless, its parameters appear to be appropriate and conservative.

Option 1 lists the applicable methane concentration limit and corresponding flux rates (as sourced from State and Territory guidelines and represent the most stringent requirement since 24 March 2011). These values could be specified by environmental regulators differently for the *final cover area* and *intermediate cover area* of a landfill. It is noted that the intermediate cover area is likely to be more permeable and temporary than the final cover area. These methane concentration limits and the corresponding flux rates may be updated periodically if applicable methane concentration limits become more stringent.

The documents that are the basis of the tables in subclauses 4(2) and 4(3) are:

- Queensland Department of Environment and Heritage Protection - *Guideline—Landfill siting, design, operation and rehabilitation.*
- NSW Environmental Protection Agency - *Environmental Guidelines: Solid Waste Landfills.*
- EPA Victoria - *Siting, Design, Operation and Rehabilitation of Landfills.*
- EPA South Australia - *EPA Guidelines: Environmental management of landfill facilities (municipal solid waste and commercial and industrial general waste).*
- EPA Tasmania - *Landfill Sustainability Guide.*
- Northern Territory EPA - *Guidelines for the siting, design and management of solid waste disposal sites in Northern Territory.*

> Conclusion 31 In terms of whether the 30 per cent default regulatory proportion defined in section 28 of the Methodology is supported by clear and convincing evidence, the authors of this report have not been able to assess all the source of information that underpin that statistic. Nevertheless, the input parameters (which are available) appear to be appropriate.

5 ASSESSMENT OF WHETHER ESTIMATES, PROJECTIONS OR ASSUMPTIONS ARE CONSERVATIVE

Summary:

This section assesses the conservativeness of relevant estimates, projections or assumptions in the Methodology.

5.1 Whether all estimates, assumptions and projections used in the method are appropriate and conservative (i.e. the values are more likely to underestimate than over estimate abatement). Where one or more estimates, assumptions or projections are not conservative, whether the overall calculation of the net abatement amount is conservative.

In section 4.1.5, an assessment was performed of whether there is clear and convincing evidence to support the appropriateness and conservativeness of all estimates, assumptions, and projections used in the Methodology. Reference should therefore first be made to the previously answered requirement. To summarise the key estimates and assumptions included within the Methodology:

- Baseline abatement
- Landfill gas calculations and non-carbon tax percentage
- Methane fraction in the landfill gas
- Energy content of landfill gas
- Oxidation Factor
- Methane destruction efficiency
- Electrical efficiency of internal combustion engine
- Global warming potential of methane

Of the above estimates or assumptions, all can be considered appropriate and most are conservative. The following sub-sections further assess each of these and where relevant alternative assumptions are included in a sensitivity analysis.

5.1.1 Baseline abatement

The 30% default baseline previously discussed in section 2.2.4 and is considered to be conservative. It is not further assessed here.

5.1.2 Landfill gas (solid waste) calculator and non-carbon tax percentage

NGER calculations for emissions from landfills are well established and provide a common basis to assess the GHG emissions from landfill operations. The Solid Waste Calculator has been updated to reflect changes in the NGER legislation affecting the 2016-2017 reporting period.

Under the carbon price and subsequently the NGER calculations for emissions arising from solid waste deposited at landfills could be deemed to be conservative. As such, some of the assumptions in the landfill gas calculator for the decomposition rates (and hence methane generated) are reasonably likely to be conservative. This is expected, so that NGER reporters do not under-estimate emissions from landfill operations. Key assumptions within the solid waste calculator have not changed during the non-carbon tax years, hence when working out the fraction to be removed from calculated abatement, the modelling approach is the same. Further assessment on the appropriateness of the non-carbon tax percentage is included in section 2.2.

5.1.3 Methane fraction in the landfill gas

The methane fraction in landfill gas has a default value of 50% which is the same is in the NGER (Measurement) determination and as used in the CDM, it could therefore be deemed appropriate. Whether this is conservative or not will depend on the age and composition of waste deposited at the landfill. The amount of air drawn into the gas capture system will also impact the methane concentration. It is therefore possible that the default value is not always conservative. However, there will also be many circumstances where methane concentration in landfill gas is higher than 50% and can be as high as 60% or more. This would make the methane fraction conservative.

5.1.4 Energy content of landfill gas

The energy content of landfill gas is based on robust measurement methods as defined in the NGER (Measurement) determination. These can be considered to be conservative but also are likely to be an accurate measure of energy content as they are based on scientific methods.

5.1.5 Oxidation Factor

The oxidation factor provided in the NGER (Measurement) Determination subsection 5.4(1) is 0.1 (or 10%). It is unclear from the Determination what the reference or basis for this is, although we are informed that it is based on the IPCC's waste guidance. Regardless, it is an important estimate and assumption that is used in the abatement calculations. If, for example, a higher oxidation factor of 15% or 20% was assumed, then the calculated abatement could be over-estimated for the period that the methane destruction device is offline.

5.2 In giving consideration to the above, an assessment of the baseline calculations is required. In particular, the assessment should examine equation 12 of the method to determine whether it will result in a conservative estimation of abatement. Where a problem is identified the service provider should identify an appropriate solution.

The landfill gas project baseline abatement (net abatement) for the reporting period is determined using Equation 12 in section 28 (Part 4 Division 4) for the 2015 Methodology. The baseline abatement is the methane combusted during the project and generated by non-carbon tax waste, multiplied by the proportion of methane that would have been combusted without the project.

The baseline reduces the number of ACCUs the project receives, based on the volume of gas that would have had to be captured for regulatory purposes had the project not been accredited under the ERF.

The application of a baseline effectively forms part of the *regulatory additionality test*. It determines how many ACCUs can be created based on how much gas would need to be captured to meet regulatory requirements. It is noted that it is not possible to capture all the gas from a landfill (refer to section 6.2). Regulatory requirements for gas capture vary greatly between jurisdictions and between sites, as described in section 2.1.3.

The net abatement therefore requires:

a) determination of the regulatory proportion,

b) default baseline proportion and

c) baseline proportion.

The determination of the abovementioned proportions depends on the type of project, as shown in Figure 12:

- Equation 12 refers to equations 13 to 16, and
- Equation 14 refers to equations 17 to 19.

This is, the baseline abatement for the reporting period, in tonnes CO_2-e, is (***equation 12***):

$$A_B = M_{Com,NCT} \times W_B$$

where:

- $\boldsymbol{A_B}$ means the baseline abatement for the reporting period, in tonnes CO_2-e.
- $\boldsymbol{M_{Com,NCT}}$ means the methane combusted during the reporting period that was not generated from carbon tax waste, in tonnes CO_2-e, worked out using equation 3.
- $\boldsymbol{W_B}$ means the proportion of the methane combusted during the reporting period that would have been combusted without the project worked out using whichever of equations 13 to 16 applies.

For the proportion of methane that would have been combusted without the project, this is either:

A. For new or recommencing project

If the project is a new project or a recommencing project, the proportion of the methane combusted during the reporting period that would have been combusted without the project is worked out using the formula (***equation 13***):

$$W_B = Maximum(W_{B,Reg}, W_{B,Def})$$

where:

- $\boldsymbol{W_B}$ means the proportion of the methane combusted during the reporting period that would have been combusted without the project.
- $\boldsymbol{W_{B,Reg}}$ means the regulatory proportion of the methane combusted during the reporting period that would have been combusted without the project as determined using Schedule 1 to this determination.
- $\boldsymbol{W_{B,Def}}$ means the default proportion of the methane combusted during the reporting period that would have been combusted without the project, which is as follows:

(a) 0% if the project proponent can demonstrate that, since 24 March 2011, the landfill concerned has not been subject to:

(i) legislation or regulatory guidelines for landfill; or

(ii) a licence condition or development approval that includes any form of general or specific qualitative requirement to collect, control, manage or limit landfill gas, methane odour or greenhouse gases;

(b) otherwise—30%.

B. Upgrade project

If the project is an upgrade project, the proportion of the methane combusted during the reporting period that would have been combusted without the project is worked out using the formula (***equation 14***):

$$W_B = Maximum(W_{B,Reg}, W_{B,Def}, W_{B,Ex})$$

where:

- W_B means the proportion of the methane combusted during the reporting period that would have been combusted without the project.
- $W_{B,Reg}$ means the regulatory proportion of the methane combusted during the reporting period that would have been combusted without the project determined using Schedule 1 to this determination.
- $W_{B,Def}$ has the same meaning as in subsection (1).
- $W_{B,Ex}$ means the proportion of the methane combusted during the reporting period that would have been combusted without the upgrade project worked out using equation 17.

Equations 17 to 19 detail the proportion of methane that would have been combusted without upgrade.

C. Transitioning projects

If the project is a transitioning project that was operating under the Carbon Credits (Carbon Farming Initiative) (Capture and Combustion of Methane in Landfill Gas from Legacy Waste) Methodology Determination 2012 (the legacy determination), the proportion of the methane combusted during the reporting period that would have been combusted without the project is worked out using the formula (***equation 15***):

$$W_B = R_P$$

where:

- W_B means the proportion of the methane combusted during the reporting period that would have been combusted without the project.
- R_P means R_P as worked out under the legacy determination.

If the project is a transitioning project that was operating under the Carbon Credits (Carbon Farming Initiative) (Capture and Combustion of Methane in Landfill Gas from Legacy Waste: Upgrade Projects) Methodology Determination 2012 (the legacy upgrade determination), the proportion of the methane combusted during the reporting period that would have been combusted without the project is worked out using the formula (***equation 16***):

$$\mathrm{W_B} = \mathrm{B_P} \; W_B = B_P$$

where:

- W_B means the proportion of the methane combusted during the reporting period that would have been combusted without the project.
- B_P means B_p as worked out under the legacy upgrade determination.

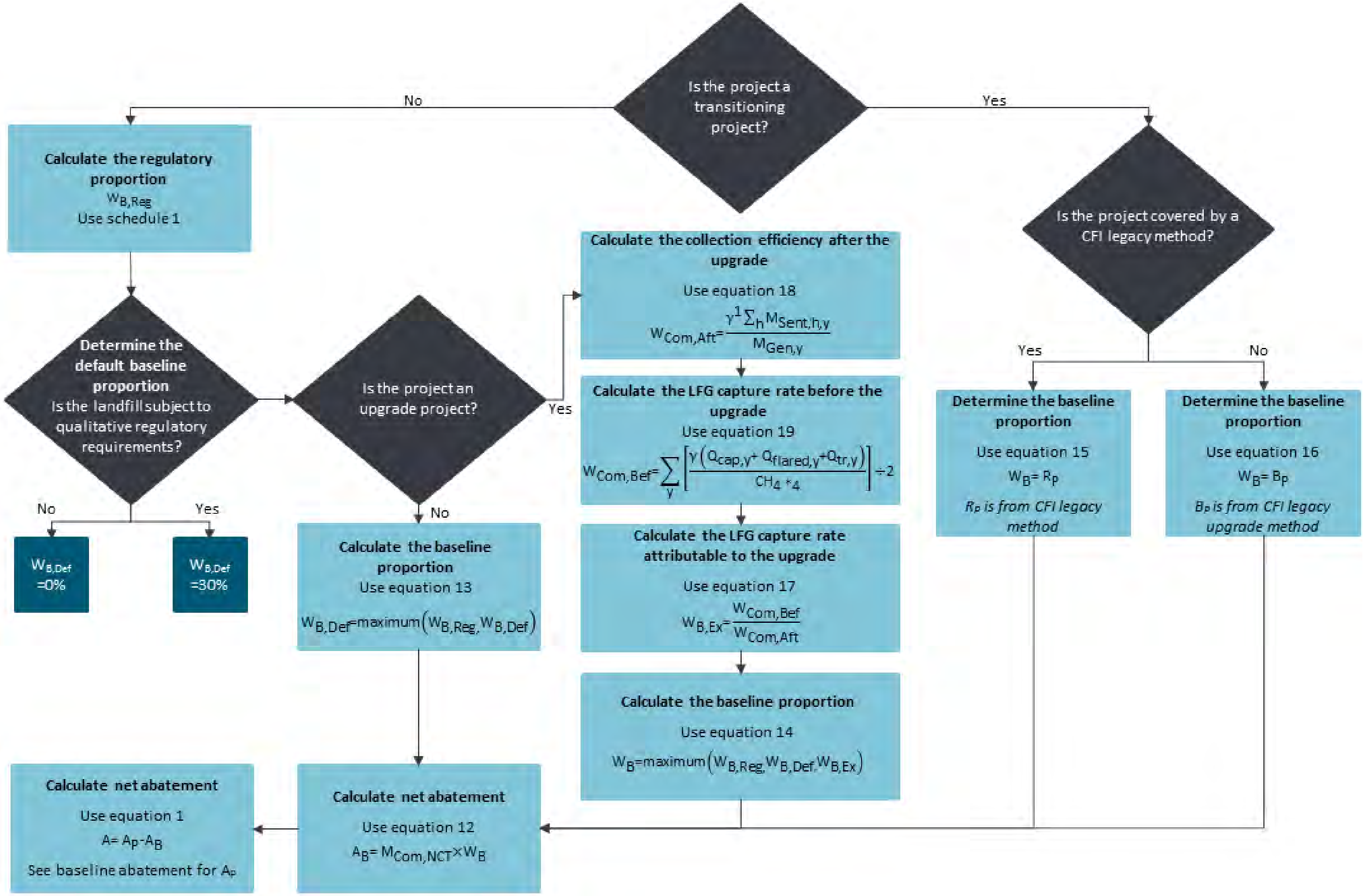

Figure 12: Equation flowchart – baseline abatement (CER, 2015)[52]

[52] Clean Energy Regulator (2015), "Participating in the Emissions Reduction Fund: A guide to the landfill gas method 2015", retrieved on 20 August 2017 from: http://www.environment.gov.au/climate-change/emissions-reduction-fund/methods/landfill-gas

This approach (i.e. Equation 12, referring to Equations 13 to 16, and Equation 14 referring to Equations 17 to 19), forms a logical and valid set of net abatement baseline equations. Equation 12 is straightforward, and Equations 13 to 19 are relatively straightforward, and the logic tests to determine which of these equations is applicable are clear. Whether the resulting baselines are conservative depends on which equation is used:

- The regulatory baseline (i.e. 0% or 30%) is reviewed in section 2.4.1 of this report.
- The case of a quantitative baseline (which may be over 50% if, for example; the landfill is in Victoria or the ACT) is reviewed in sections 2.2.4.3 and 2.5.1 of this report.
- In the case of previous CFI and upgrade projects (which represent the majority of ERF landfill gas projects as shown in Figure 13) whether the baselines are conservative is perhaps of limited relevance, because the 'grandfather' right to use those original baselines is not in question, at least for the initial crediting period. An analysis of those baselines would be useful, but would require baseline data from those projects.

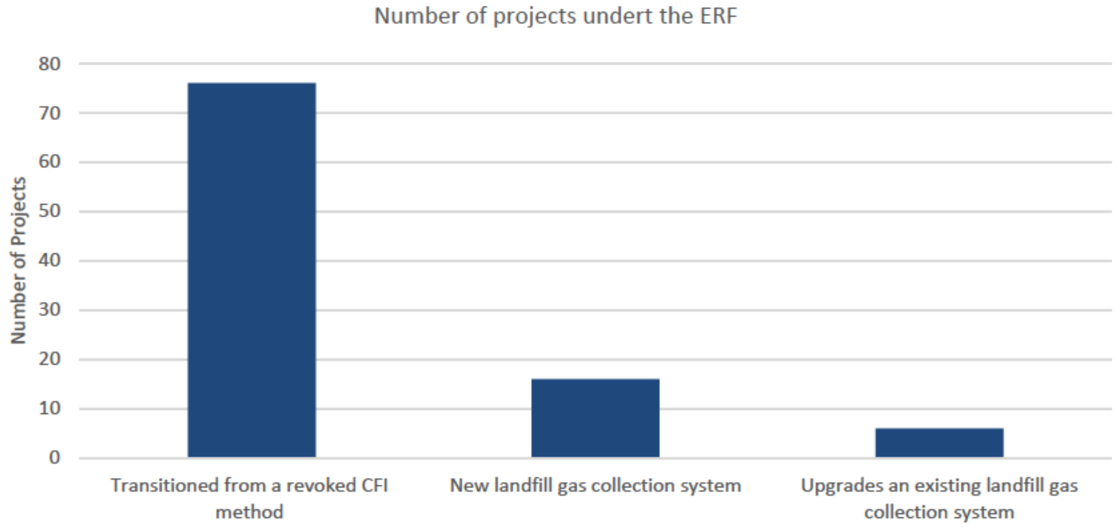

Figure 13: Numbers of landfill gas projects in the ERF project register (by type), 9 October 2017

Conclusion 32 The baseline abatement can be quantified using the calculation approaches set out in equations 12 to 19 of the Methodology. These equations are straightforward and their logic is clear. The ongoing 'grandfathered' baselines for pre-existing CFI projects may or may not be conservative, but the ability to use them is a clear legislative right.

6 PROVIDE DATA AND AN ANALYSIS OF LANDFILL GAS CAPTURE AND COMBUSTION PROJECTS

6.1 For as many Australian landfills as reasonably possible, a table providing:

6.1.1 Landfill size (tonnes waste received per year and tonnes emissions in CO_2-e per year) and location (state and city/town)

Landfill size data (tonnes waste received per year) does not appear to be collected on a routine basis by either the Federal or State Governments. Therefore, to obtain this information it was necessary to conduct a detailed literature review to collate data for relevant landfill sites in Australia. This section provides the main findings and highlights from this literature review. Additional supporting information, assumptions, and data analysis is provided in a separate excel file provided to the DoEE (Annexe C).

Information on waste management facilities was obtained from the Australian Government (Geoscience Australia). The information considers different site types and include multi-purpose facilities, landfills, transfer stations and reprocessing facilities. A summary of this information is provided in section 6.1.1.1.

Furthermore, the Waste Management Association of Australia (WMAA) undertakes surveys of landfills in Australia. SMEC understands that surveys were undertaken in 2006-07; in 2008; and in 2010. The surveys were similar but extra questions were added each time. Response rates have varied. Relevant results from analysis of the landfill survey data are provided in section 6.1.1.2 as derived from the Blue Environment[53] report to the DoEE. It should be noted that this data is several years old and therefore some of this may be out of date (e.g. new and closed landfills). Nonetheless, it provides useful context to the landfills in Australia and highlights potential data gaps.

6.1.1.1 Waste Management Facilities in Australia

This data includes a total of 2,291 waste management facilities in Australia, as shown in Table 16. It is noted that the database accounts for all facilities in Australia, including:

- non-operational sites;
- different landfills in the same site (i.e. a site can account for multiple facilities); and
- considers sites which used to be a landfill and ceased landfilling activities but are operating transfer stations (i.e. considered as two different facilities).

As such, there are some differences with the data provided in section 6.1.1.2, in particular the NT and QLD.

[53] Blue Environment (2013). Analysis of landfill survey data. Prepared for WMAA. Available from: https://www.environment.gov.au/system/files/resources/91763f0e-f453-48d0-b33e-22f905450c99/files/landfill-survey-data.pdf

Table 16: Waste Management Facilities in Australia[54]

Site Type	Total	NSW	VIC	NT	WA	SA	QLD	TAS	ACT
Multi-Purpose	241	101	45	4	29	24	35	2	1
Landfill	1,166	263	156	140	254	109	226	17	1
Transfer Station	755	138	195	9	51	96	196	68	2
Reprocessing	129	53	36	1	10	7	14	1	7
Total Sites	2,291	555	432	154	344	236	471	88	11
% Landfill per State		*23%*	*13%*	*12%*	*22%*	*9%*	*19%*	*1%*	*0%*

Figure 14 provides a visual representation of geographic spread of waste management facilities. Landfills are diverse in size and are dispersed across Australia. It is noted that:

- **Most the larger landfill sites are located near dense population areas which have higher rainfall levels.**
- **These landfills will have the greatest landfill gas production and potential for odour.**
- **These landfill sites are the most likely to have local community pressure to manage the landfill gas.**

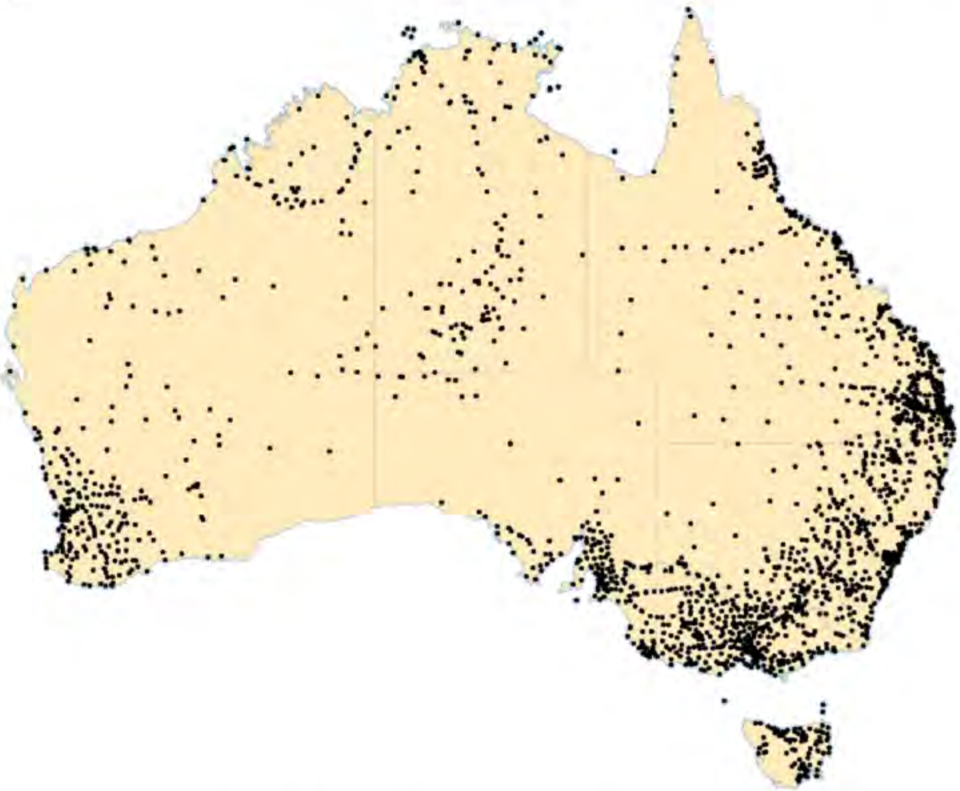

Figure 14: Waste Management Facilities location[55]

[54] Source: Australian Government, Geoscience Australia, 2017, Waste Management Facilities_v1.1.xls, downloaded from https://ecat.ga.gov.au/geonetwork/srv/eng/search#!a66ac3ca-5830-594b-e044-00144fdd4fa6 on 24 July 2017.

[55] Source: Australian Government, Geoscience Australia, 2017, Waste Management Facilities. Accessed on 24 July, 2017 from: http://www.ga.gov.au/metadata-gateway/metadata/record/72592/

6.1.1.2 Landfill sizes and distributions

Sites can be classified into size groups through reference to their reported annual inputs or through reference to the population serviced. Table 17 provides a summary of the clarification.

Table 17: Size classifications (Blue Environment, 2013)

Size class	Annual tonnes	Population serviced	Average tonnes/person in size class based on known data
Very small	≤1,000	≤250	0.19
Small	1,001 to 20,000	250 to 5,000	0.18
Medium	20,001 to 100,000	5,000 to 50,000	0.56
Large	≥100,000	≥50,000	0.48

The bulk of Australia's landfill sites are small or very small. Thirty-eight sites (8%) are known to be large and 78 (16%) are known to be medium. The 21% of unknown size are likely to be mostly small or very small (see Figure 15).

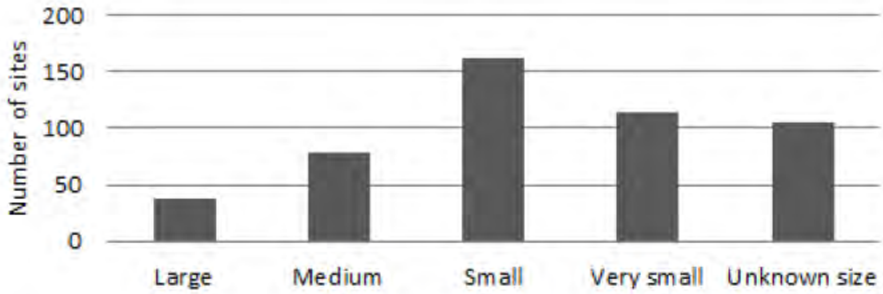

Figure 15: Reported numbers of Australian landfills by size class (Blue Environment, 2013)

Queensland reports the most sites, followed by New South Wales and Western Australia (refer to Figure 16). This is consistent with the land size and population distribution in each of these jurisdictions.

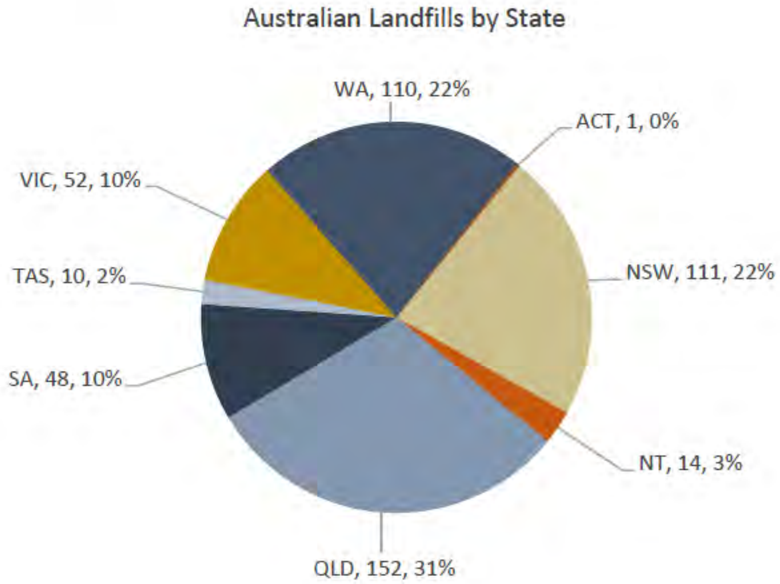

Figure 16: Reported numbers of Australian landfills by jurisdiction (Blue Environment, 2013)

Queensland, Western Australia and South Australia have relatively high proportions of small landfills. This matches their highly-dispersed populations. Victoria and Tasmania have a high proportion of large and medium sites. NSW has most large sites matching its relatively large population.

The 8% of Australia's landfills that are classified as large accept 75% of the waste. These are the sites servicing the major cities. Medium-sized landfills accept 20% of the waste, small sites receive 5% and the very small sites accept only 0.2%. This data is summarised by State in Table 18.

Table 18: Millions of tonnes received per year by jurisdiction & landfill size class (Blue Environment, 2013)

State	Large	Medium	Small	Very Small	All sizes
NSW & ACT	4.68	1.05	0.21	-	5.93
NT	-	0.07	-	-	0.07
QLD	3.33	0.87	0.26	0.01	4.47
SA	0.47	0.12	0.11	-	0.71
TAS	0.29	0.17	0.01	-	0.46
VIC	2.07	0.45	0.13	-	2.65
WA	1.72	0.58	0.13	0.01	2.44
Total	12.56	3.31	0.85	0.02	16.73

6.1.1.3 Landfill sizes and GHG emissions

The CER provided SMEC with data on landfill sites in Australia which included the 'facility name', 'state', and the 'total emissions from the landfill facility (tCO_2-e) per annum' from 2008-09 to 2015-16. This data is derived from NGER reporting and potentially data from State Governments.

In order to use this data, it was necessary to perform several manipulations, data cleansing, and a detailed assessment of the data quality and relevance. The steps taken to make the data presentable for the purposes of addressing this requirement can be summarised as follows:

1. Reviewed each facility to merge or remove any duplications. For example, some facilities are reported under different names in different years, hence this data was merged.
2. If a facility only has one year of reported data it was removed from further assessment as these appeared to be either anomalies, or were not considered to provide robust data. For example, there appears to be many facilities that have only reported in 2008-09, it is not clear why but could be to do with the introduction of NGER reporting.
3. To estimate the 'typical' emissions per year, an average of the available years was taken with outliers removed. It should be noted that several landfills have closed in this period, therefore their emissions profiles could be expected to change and hence historical data may not be fully reflective of current or future emissions (i.e. the landfill could be capped at the end of its life).
4. There are many landfill sites where data is reported in one or some years, but not all. This could be because:
    - the reporting threshold is not triggered, or
    - an issue with the data quality in prevalent.
5. From the data provided and our subsequent analysis of landfill gas combustion projects, it is apparent that the DoEE data is missing a lot of landfill sites. This could be because they are

below reporting thresholds, or because the names of the gas combustion projects do not easily correlate to the landfill name. Wherever possible we have matched the emissions data with other relevant data on the landfill (see sections 6.1.2 and 6.1.3).

SMEC was provided with emissions data for 273 landfills. This was filtered down to remove outliers such as a single reported year or where sites needed to be merged (as reported under more than one name). This gave a total of 75 landfills with reasonable emissions data of 2 or more years. All of these landfills were researched using online searches to try and ascertain the tonnes of waste received per year. Of the 75 landfills, it was found that 22 had data on waste received, 15 had closed, 6 were mines, and for the remaining 39, the annual tonnages received at the landfill were unknown.

For the landfills with data, Figure 17 shows the annual average GHG emissions per year (tCO_2-e) compared to the tonnes of waste received for the 22 landfill sites analysed. This data can be further analysed to estimate the GHG emissions per tonne of waste received:

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Figure 17: Annual average GHG emissions compared to tonnes of waste received per year (22 landfills)

Analysis of this data shows a reasonable correlation between landfill size and scope 1 GHG emissions. This is in line with expectations as larger landfills have more waste and bigger surface area, hence fugitive emissions would likely be higher.

Another metric assessed is the ratio of GHG emissions divided by the tonnes of waste received. This gives an indication of the relative GHG emissions of different sized landfills, as shown in Figure 18. To obtain this data the 22 landfill sites were categorised into those receiving less than 100 kt/yr, 100-300 kt/yr, and greater than 300 kt/yr. These tonnages relate to the small/medium, large, and very large size respectively.

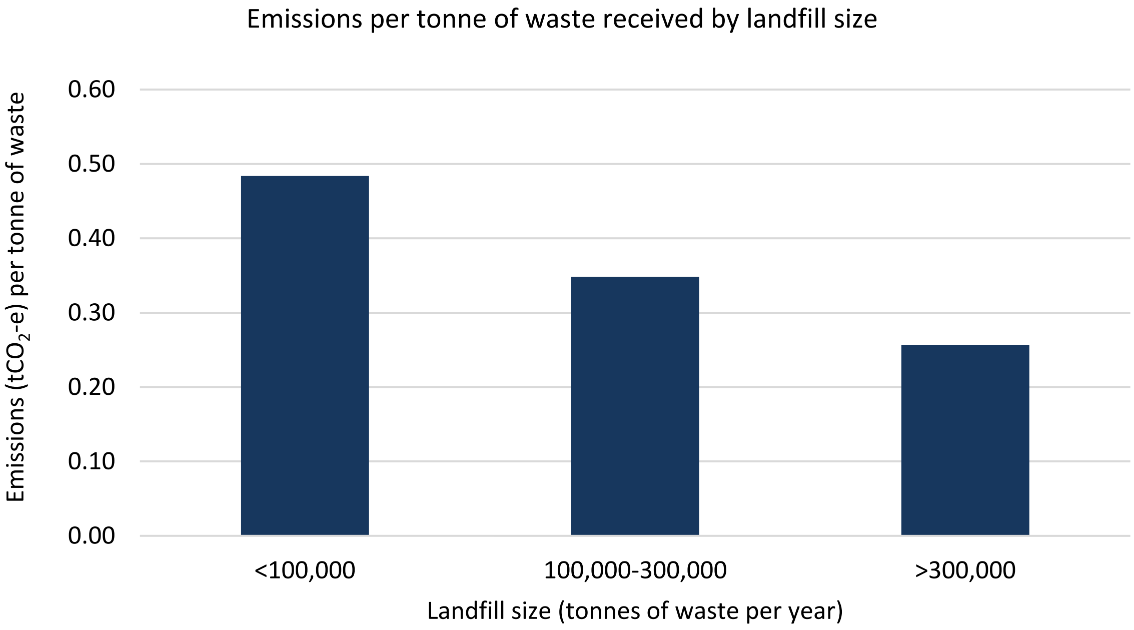

Figure 18: Emissions per tonne of waste received by landfill size

Using this data, the GHG emissions per tonne of waste was categorised by State. This shows that Western Australia has the largest emissions per tonne received, whilst Victoria has the lowest (see Figure 19).

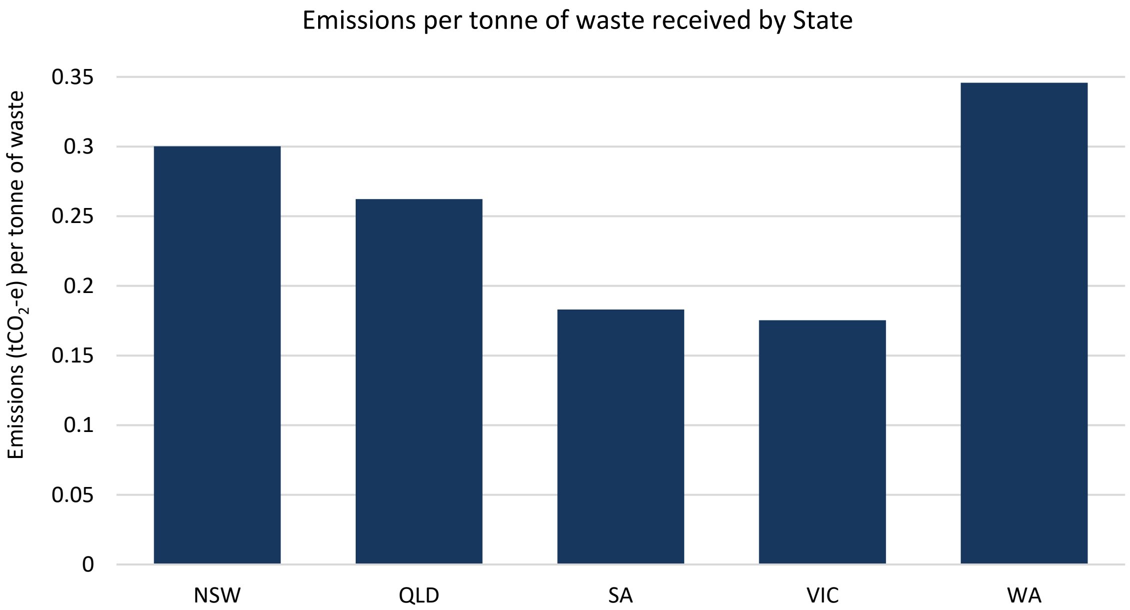

Figure 19: Emissions per tonne of waste received by State

The data obtained for the 22 sites where waste received tonnes were determined is provided in Table 19.

Table 19: Landfills by name and location with tonnage and emissions data

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Conclusion 33 The data obtained shows a trend that bigger landfills have higher emissions which would be expected. However bigger landfills also tend to capture more of the landfill gas so the emissions per tonne of waste received is in general lower for larger landfills.

Conclusion 34 Data on landfill tonnes per annum can be very difficult to obtain in the public domain. For some landfills, it was possible to obtain this data from literature searches, however whilst all sites were searched for it is apparent that this information is not readily available. It is therefore recommended that the state and federal Governments try to collate this information together so it is more available.

Conclusion 35 Scope 1 GHG emissions data for landfills provided by the CER highlights some issues in this data collection and quality. For instance, there are a significant number of facilities that have only reported for one year, not all years, or stop reporting altogether. There could be valid reasons for this such as being below a reporting threshold, change of name, data missing, etc. however it would be expected that landfills should have relatively consistent emissions profiles year on year so some further investigation into the scope 1 emissions reported under NGER or State Governments should be undertaken.

Conclusion 36 For ERF projects the waste received at a landfill (split by waste type / composition) is required for calculated abatement. It would be useful if the CER or DoEE collated this information so further analysis can be performed of different landfill characteristics.

6.1.2 Whether or not the landfill has one or more gas capture systems, and mode of landfill gas destruction (whether flare, combustion engine, boiler or other device)

Data obtained from the CER included landfill gas captured for some facilities. It was noted that several landfills that were known to capture landfill gas did not have data on the total methane captured. This maybe because:

- State Governments do not collect this information;
- due to reporting thresholds; or
- how the data is managed.

The initial focus of the analysis of gas capture was therefore on those sites which were included in the data obtained. To analyse gas capture rates, the following steps were taken:

1. Landfill facility data was filtered to only include sites where landfill gas capture data was included.
2. The data was manipulated to merge any sites which were reported under more than one year.
3. The data was combined with the GHG emissions data to give the capture rates for different landfill facilities.

4. The volume of landfill gas flared data was very limited. Only a few sites had this data for more than one year. Therefore, this data was not further assessed.
5. Average landfill gas capture rates were determined and compared to other data sets including the ERF project registry.

From the CER data, there were 34 landfill facilities with total methane captured data. Combining this data with GHG emissions data and tonnes of waste received produced results as summarised in Table 20.

For the 34 landfill facilities, it was possible to determine the tonnes of waste received for 15 sites, 13 have closed, and tonnage was unknown for the remaining 6 locations. Of the 34 sites with gas capture data, 18 were registered with ERF projects, the remaining 16 were labelled as *unknown*. It is noted that these unknown sites could have projects but the names of the landfill do not match the ERF project name. Four (4) of the landfills have two (2) ERF projects (i.e. Eastern Creek Landfill, Lucas Heights, Woodlawn Bioreactor, and the Ti Tree Bioreactor). As such, a total of 38 projects were considered.

With regards to the type of combustion device at each location, it was possible to derive if it is 'flare only' from the ERF register. It was also possible to ascertain if the site has an engine through analysis of the REC registry (see section 6.1.3). Figure 20 summarises the analyse of the 38 combustion devices where DoEE have provided capture data.

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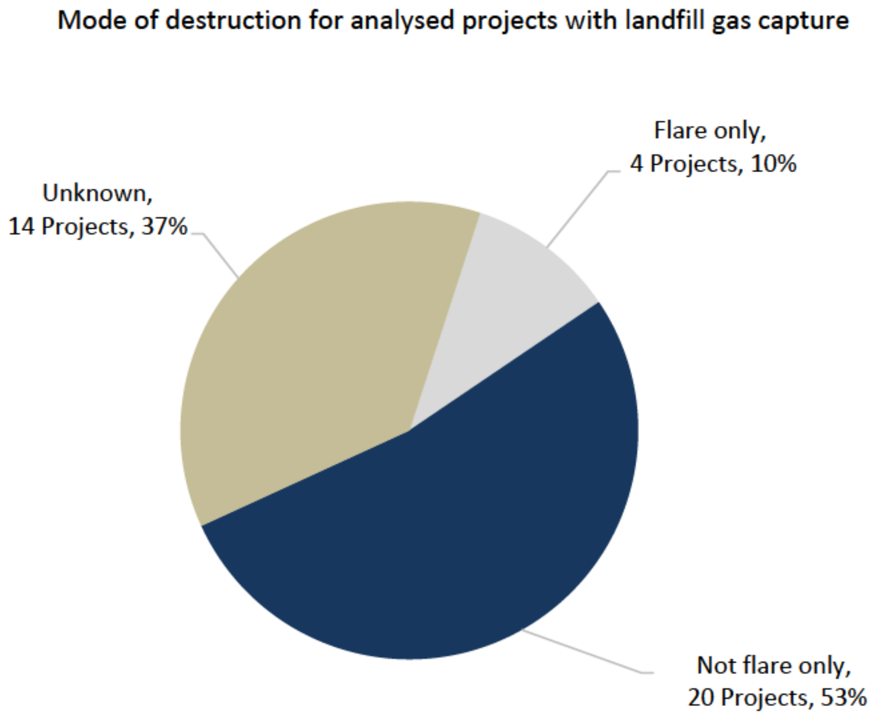

Figure 20: Analysis of the mode of destruction for 38 projects with landfill gas capture data

The following is noted:

- 14 of the projects were categorised as '*unknown*' because it was not possible to match them to either the REC or the ERF registers.
- 17 of the projects listed as '*not flare only*', were matched to the REC registry and it was concluded that they would have a combustion engine.

It could be considered that almost all the '*not flare only*' projects have internal combustion engines (i.e. rather than boilers) as:

- finding a heat use at a landfill site could be difficult; and
- the financial driver of electricity generation is in general the most economic use of landfill gas.

There were some anomalies in the data provided by the DoEE that warranted additional investigation. Firstly, there were several sites that were known to either have RECs or be registered as an ERF project, therefore it is not clear why no capture data was available for these sites. To assess those sites that were registered ERF projects a review of the ERF project register was conducted. Table 21 summarises the sites that did not have landfill gas capture data but were identified as ERF projects.

Table 21: Landfill sites without landfill gas capture data but identified as ERF projects

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There are 102 projects on the ERF register, of these 18 were identified as included in the DoEE data for landfill gas capture. A further 14 were identified has having emissions data but not gas capture data. There were also 4 landfills that had two ERF projects on the same landfill. This gives a total of 36 ERF projects that could be matched to the emissions and gas capture data provided by the DoEE. It is possible that more landfills are included but that they don't have more than one year of emissions data or could not be identified using the ERF project name. This does leave a significant amount of ERF projects that don't appear to have good quality data for emissions or gas capture collected by the DoEE. A likely reason for this is that they are below reporting thresholds for NGER, or that the ERF project has a different name to the landfill. There are also several ERF projects that have not yet generated any ACCUs.

For the landfills with landfill gas capture data further analysis was undertaken. Firstly, an assessment of the correlation between gas capture rate (%) and landfill size was conducted. This analysis excluded those sites that were closed or the tonnages were unknown, so a total of 15 landfills were included in the sample. The gas capture rate was determined by taking the average for each year where data was available. Figure 21 shows a scatter plot comparing landfill size with the gas capture rate.

Average gas capture ratio compared to tonnes of waste received p.a.

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Figure 21: Average gas capture rate (%) for different landfill sizes (tonnes of waste received per year)

It is noted that it was not possible to validate the data quality of the information provided by the CER. For example, some outliers were included, there are missing years of data. A key assumption was made; that the gas capture rate is determined by dividing "total gas captured" by "total emissions" (i.e. landfill emissions plus gas captured). If the data was available, further analysis could be performed on the age of the landfill, emissions rates, and capture rates for open and closed landfills. Further assessment is not possible based on the data available.

6.1.2.1 ERF register and ACCU data

An assessment was performed of the ERF register to assess the ACCUs generated by different projects. The available ACCU data has some limitations (e.g. the reporting period covered is not known). ACCUs are issued following the approval of an offsets report and all projects have different dates and reporting periods. Nonetheless, it is possible to derive useful information of relevance to this assessment.

Firstly, of the 102 ERF projects, it is apparent that 86 project have generated ACCUs. A total of 13.2m ACCUs have been issued over the period from 2012/13 to 2016/17. This gives an average of over 150,000 ACCUs per project, which equates to over 30,000 ACCUs per project per year. It is noted that this data set is likely to have inaccuracies as not all projects commenced in 2012/13 and not all ACCUs up to the current date have been issued. Alternatively, if it is assumed that the average project length to date is 3 years (i.e. not 5 years) then, the average per project would be 50,000 ACCUs per year.

If it is assumed that all projects have a 30% baseline and other project emissions are not material, then the total gas captured (gross abatement) is on average just over 70 ktCO_2-e per annum. Comparing this to the DoEE data the average gas capture over the period between 2012/13 to 2015/16 is over 150 ktCO_2-e per annum. The difference is likely to be explained by smaller landfills that do not report under NGER and hence would give a lower average gas capture rate.

6.1.3 Whether the landfill is generating credits under the Renewable Energy Target or exporting electricity generated from the combustion of landfill gas

Details of landfill gas projects that are generating credits under the RET can be derived from the REC registry, available at: https://www.rec-registry.gov.au/rec-registry/app/home

The registry was reviewed and all landfill gas projects were extracted into a database. Each of these was matched to an ERF project if possible. There were a total of 66 projects included in the REC registry, of these it was possible to match 41 to ERF projects. For the remainder of 25 it is possible these are also ERF projects under a different name. It is anticipated that as all 66 projects are generating credits under the Renewable Energy Target, then these are also exporting electricity generated from the combustion of landfill gas. No further data was available for analysis. Table 22 summarises the project data from REC registry matched to the ERF register.

Table 22: REC Registry landfill gas projects

State	Name	Company	ERF Project
ACT	Belconnen LFG Power Plant	EDL LFG (ACT) Pty Ltd	Yes
ACT	Mugga Lane LFG Power Plant	EDL LFG (ACT) Pty Ltd	Yes
NSW	AGLSITA1– LFG - NSW	AGL Energy Services Pty Limited	Unknown
NSW	Kincumber LFG - NSW	AGL Energy Services Pty Limited	Yes
NSW	West Nowra Landfill Gas	AGL Energy Services Pty Limited	Yes
NSW	Woy Woy LFG - NSW	AGL Energy Services Pty Limited	Yes
NSW	Belrose LFG Power Plant	EDL LFG (NSW) Pty Ltd	Yes
NSW	Eastern Creek LFG Power Plant	EDL LFG (NSW) Pty Ltd	Yes
NSW	Grange Avenue Power Station	EDL LFG (NSW) Pty Ltd	Yes
NSW	Jacks Gully	EDL LFG (NSW) Pty Ltd	Yes
NSW	Lucas Heights I & II LFG Power Plant	EDL LFG (NSW) Pty Ltd	Yes
NSW	Albury LFG - NSW	LMS Energy Pty Ltd	Yes
NSW	Awaba - LFG - NSW	LMS Energy Pty Ltd	Yes
NSW	Buttonderry LFG - NSW	LMS Energy Pty Ltd	Yes
NSW	Eastern Creek 2 LFG - NSW	LMS Energy Pty Ltd	Yes
NSW	Stotts Creek - Landfill Gas (LFG) - NSW	LMS Energy Pty Ltd	Unknown
NSW	Summer Hill (Wallsend) LFG - NSW	LMS Energy Pty Ltd	Yes
NSW	Macarthur Resource Recovery Park - Biomass based components of MSW-NSW	SITA Australia Pty Ltd	Unknown
NSW	Woodlawn Bioreactor LFG - NSW	Woodlawn Bioreactor Energy Pty Ltd	Yes
NT	Shoal Bay LFG - NT	LMS Energy Pty Ltd	Yes
QLD	Browns Plains LFG Power Plant	EDL LFG (Qld) Pty Ltd	Yes
QLD	Roghan Road LFG	EDL LFG (Qld) Pty Ltd	Yes
QLD	Sleeman Sports Centre LFG QLD	Energy Impact Pty Ltd	Unknown
QLD	Dakabin LFG-QLD	Landfill Gas Industries P/L	Unknown
QLD	Gladstone LFG-QLD	Landfill Gas Industries P/L	Yes
QLD	Maryborough LFG-QLD	Landfill Gas Industries P/L	Yes
QLD	Willawong - LFG - QLD	Landfill Gas Industries P/L	Yes
QLD	Birkdale LFG - QLD	LMS Energy Pty Ltd	Yes

State	Name	Company	ERF Project
QLD	Molendinar Landfill	LMS Energy Pty Ltd	Yes
QLD	Reedy Creek	LMS Energy Pty Ltd	Yes
QLD	Rochedale LFG	LMS Energy Pty Ltd	Yes
QLD	Stapylton LFG	LMS Energy Pty Ltd	Yes
QLD	Suntown Landfill Power Station	LMS Energy Pty Ltd	Yes
QLD	Swanbank Renewable Energy - LFG - QLD	LMS Energy Pty Ltd	Yes
QLD	Whitwood Road LFG	LMS Energy Pty Ltd	Unknown
QLD	Swanbank	Stanwell Corporation Limited	Unknown
QLD	Ti Tree LFG Willowbank - QLD	Veolia Environmental Services (Australia) Pty Ltd	Yes
SA	Pedler Creek LFG Power Plant	EDL LFG (SA) Pty Ltd	Yes
SA	Wingfield I & II LFG Power Plant	EDL LFG (SA) Pty Ltd	Unknown
SA	Highbury LFG Power Plant	EDL Operations (Highbury) Pty Ltd	Unknown
SA	Tea Tree Gully LFG Power Plant	EDL Operations (Tea Tree Gully) Pty Ltd	Unknown
TAS	Glenorchy LFG - TAS	AGL Energy Services Pty Limited	Yes
TAS	McRobies Road - Landfill Gas (LFG) - Hobart - TAS	AGL Energy Services Pty Limited	Yes
TAS	Mowbray - LFG - TAS	LMS Energy Pty Ltd	Unknown
VIC	Berwick LFG Power Plant	EDL LFG (Vic) Pty Ltd	Unknown
VIC	Broadmeadows LFG Power Plant	EDL LFG (Vic) Pty Ltd	Unknown
VIC	Brooklyn LFG Power Plant	EDL LFG (Vic) Pty Ltd	Yes
VIC	Corio LFG Power Plant	EDL LFG (Vic) Pty Ltd	Unknown
VIC	Springvale & Clayton LFG Power Plant	EDL LFG (Vic) Pty Ltd	Unknown
VIC	Transpacific LFG - Truganina VIC	Landfill Operations Pty Ltd	Yes
VIC	Cosgrove LFG - Vic	LMS Energy Pty Ltd	Unknown
VIC	Eaglehawk - LFG - VIC	LMS Energy Pty Ltd	Unknown
VIC	Hampton Park - LFG - VIC	LMS Energy Pty Ltd	Unknown
VIC	Mornington Landfill	LMS Energy Pty Ltd	Yes
VIC	Smythesdale LFG - VIC	LMS Energy Pty Ltd	Unknown
VIC	Wollert-Landfill Gas (LFG)-VIC	LMS Energy Pty Ltd	Yes
VIC	Wyndham Landfill	LMS Energy Pty Ltd	Yes
WA	Kelvin Road LFG	AGL Energy Services Pty Limited	Yes
WA	Millars Road LFG	AGL Energy Services Pty Limited	Yes
WA	Canningvale	LANDFILL GAS and POWER PTY. LTD.	Unknown
WA	Kalamunda Power Station	LANDFILL GAS and POWER PTY. LTD.	Unknown
WA	Red Hill Power Station	LANDFILL GAS and POWER PTY. LTD.	Unknown
WA	Tamala Park	LANDFILL GAS and POWER PTY. LTD.	Unknown
WA	Atlas WA LFG	LMS Energy Pty Ltd	Unknown
WA	South Cardup WA LFG	LMS Energy Pty Ltd	Yes
WA	Henderson/Wattleup Landfill Gas (LFG) - WA	Waste Gas Resources Pty Ltd	Unknown

6.2 Assessment, including reasoning, of the maximum percentage of landfill gas which can realistically be captured on a landfill site during operation and after the cell is capped. This must include an examination of the factors that influence the level of gas capture, including responses to the following questions:

Summary:

Key factors affecting the proportion of maximum possible gas collection are depth, width, type of waste, leachate issues, how hot the climate is, how wet the climate is, type of cap, type of lining, how well the landfill is managed is general.

The NGER Measurement Determination assumes that a maximum 75% of gas generated can be collected; actual practice anecdotally and from literature varies from zero (no collection) to under 50% for poorly managed sites to nearly 100% at sites with the most effective collection management.

Note that the percentage of gas collection is not a factor considered in the 2012 or 2015 Methods; crediting is on the basis of tons of methane above the baseline amount oxidised.

6.2.1 Does the size of a landfill affect how much gas can be captured? If so, how?

6.2.1.1 Landfill Size

Anecdotally, larger tonnage landfills tend to collect a higher portion of landfill gas. This is partly because smaller landfills may lack the economy of scale to make efficient gas collection, or indeed any gas collection, economically feasible.

For a given tonnage size, landfill physical size theoretically has a small negative impact on gas collection. This is, a physically larger but identical tonnage landfill will have a higher collection line installation cost and annual maintenance cost. This is due to the larger distances for the physically larger site.

6.2.2 What other factors influence the maximum proportion (compared to total landfill gas produced) of gas capture at a site?

Other key factors affecting the proportion of maximum possible gas collection are:

- The time since waste was deposited,
- Cell design,
- Type of waste,
- Leachate issues,
- Weather conditions how hot the climate is, how wet the climate is,
- Landfill management.

These factors are described in the below sections.

6.2.2.1 Time since waste is deposited

Immediately after waste deposition, gas generation is low and collection will be difficult and expensive per tonne. Typically, gas wells are installed when a cell is complete; collection lines are drilled vertically into the finalised waste body, so all (100%) of gas generation before that time will be lost to atmosphere. After several years of strong gas generation and collection, gas generation volumetric rate and methane concentration will decline to the point that capture is no longer economically or operationally feasible, and collection percentage will decline and then become zero when collection ceases.

6.2.2.2 Cell design and landfill management

The largest source of gas leakage into atmosphere avoiding collection pipework and possibly avoiding oxidation in the landfill cap is generally thought to occur at the boundaries between cells. In most cases cells 'lean' on each other, and the boundary, prior to filling of the subsequent cell, is intermediate cover. There is an easy (i.e. low pressure drop and high volume) path that gas can take straight to atmosphere, so the percentage of generated gas collected will be lower. The degree to which this happens depends on the landfill design (including depth, width, type of cap, type of lining, etc.), construction and operation over time.

The quality of sealing around penetrations also affects the percentage of gas not collected because of leakage at the penetration. Penetrations include leachate sumps, leachate monitoring bores and gas bores for collection pipelines.

When landfills or cells are deep, horizontal layers of pipes connected to risers may be installed. This avoids some of the leakage discussed above. The Woodlawn site at Tarago, NSW is an example of a site using this technique.

The type of cap installed will also have an effect on the potential gas collection, for example:

- A clay cap can funnel emissions to cracks, allowing greater loss to atmosphere with low levels of oxidation.
- A thick and more permeable layer, such as a phytocap, allows slow leakage, so there is less chance of cracks, slower percolation of gas through the cap and more oxidation. High levels of organic matter in the cap increases oxidation because it provides more sites for the methanogenic bacteria to work. Research based on the relative levels of C12 and C13 components in the gas stream shows the potential for oxidation rates of 40% and more[56,57].

For a completed landfill cell, most of the uncaptured gas probably exits through cracks or edges of penetrations. That means the proportion of capture is significantly dependent on the degree of monitoring (to find the leaks) and maintenance (to fix them). The maximum theoretical capture rate is high if the operator actively manages the landfill gas. The operator of the landfill gas collection equipment may not be the party determining that level of attention and expenditure.

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[56] Yoojin Jung, Paul T. Imhoff, Don C. Augenstein, and Ramin Yazdani (2009), Influence of high-permeability layers for enhancing landfill gas capture and reducing fugitive methane emissions from landfills.

[57] K. Spokas, J. Bogner, J.P. Chanton, M. Morcet, C. Aran, C. Graff, Y. Moreau-Le Golvan and I. Hebe (2005) Methane mass balance at three landfill sites: What is the efficiency of capture by gas collection systems? in Di Maria, F., Sordi, A. and Micale, C., (2013) Experimental and life cycle assessment analysis of gas emission from mechanically–biologically pretreated waste in a landfill with energy recovery. Waste Management, 33(11), pp.2557-2567

6.2.2.3 Type of waste, ambient conditions

The velocity of gas generation will depend on the type of waste (i.e. percentage of the waste that is putrescible) and ambient conditions (i.e. hotter and wetter conditions create more rapid degradation and gas generation). More rapid generation would lead to earlier economically feasible installation of collection lines.

6.2.2.4 Leachate

Higher leachate flow, meaning more putrescible material leaking from the cell with leachate water, will decrease the percentage of landfill gas collection. This is because the leachate degrades and ejects gas directly to atmosphere. Unless handled in a facility where the off gas is directed to the gas destruction equipment.

6.2.2.5 Landfill gas collection efficiency

Despite the widespread use of landfill gas collection systems in many parts of the world for over three decades with approximately 955[58] landfills collecting landfill gas worldwide[59], little information on their capture efficiency is available[60]. Such an understanding would result in more rationally designed landfill gas collection systems that might improve methane capture efficiency.

Whilst landfill gas collection rates are readily and accurately measured in the ERF landfill gas methodologies, the landfill gas generation rates (the second measurement needed for determining efficiency), are usually unknown or have a high degree of uncertainty.

Several methods have been proposed to estimate the landfill gas generation rate at a landfill, amongst them are:

- combining pneumatic well test data with assumptions about well recovery to estimate landfill gas generation[61];
- employing biokinetic models describing stages of waste decomposition[62];
- using simple first-order kinetic gas generation models such as the *Landfill Gas Emission Model* (LandGEM)[63] and the CLEEN Model[64] by Karanjekar et al (2015). This last achieves a regression R^2 value of 0.75 for a first-order methane generation rate constant value k as a function of waste composition, annual rainfall, and temperature.

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[58] As of 2007.
[59] Nickolas J. Themelis and Priscilla A. Ulloa (2007) Methane generation in landfills, Renewable Energy 32, p.1244.
[60] Jung, Y., Imhoff, P. and Finsterle, S. (2011) Estimation of landfill gas generation rate and gas permeability field of refuse using inverse modelling, Transp Porous Med 90, pp. 41–58.
[61] Emcon, A. (1980) Methane generation and recovery from landfills. Ann Arbor Science, AnnArbor, MI, USA.
[62] El-Fadel, M., Findikakis, A.N. and Leckie, J.O., (1996) Numerical modelling of generation and transport of gas and heat in landfills I. Model formulation. Waste management & research, 14(5), pp.483-504..
[63] USEPA (2005) Landfill Gas Emissions Model (LandGEM). Accessed 18 Aug 2017. Available from: https://www.epa.gov/catc/clean-air-technology-center-products#software
[64] Karanjekar, R.V., Bhatt, A., Altouqui, S., Jangikhatoonabad, N., Durai, V., Sattler, M.L., Hossain, M.S. and Chen, V., (2015) Estimating methane emissions from landfills based on rainfall, ambient temperature, and waste composition: the CLEEN model. Waste Management, 46, pp.389-398.

However, these methods suffer from significant limitations. Estimates based on pneumatic well tests rely on precise pressure measurements[65,66]. Biokinetic modelling requires biokinetic parameters and detailed data about the refuse, such as mass fractions for each waste category that are often unavailable or estimated with limited data[67]. Kinetic models also require parameters that must be estimated. These methods therefore provide only limited information or quantitative understanding.

The NGER Measurement Determination section on landfill gas uses a first order decay method to estimate methane generation. The NGER model that determines gas production from a landfill is a model known to over and under estimate actual gas production. In one anecdotal case, gas collection was more than double that modelled.

Because the quantitative estimation of landfill gas generation is challenged, trying to determine a maximum gas capture proportion for operational landfills is also challenging, and quoted recovery percentages vary widely.

A Life Cycle Analysis (LCA) study undertaken for the European Community found an average gas recovery rate in the European Union (EU) of 33%. This recovery rate was estimated based on the proportion of waste thought to be sent to landfills having gas recovery, country-specific estimates of operational gas recovery rates and an estimated proportion of emissions that occur before or after gas recovery systems are installed[68]. The study noted, however, that operational gas recovery of 70% to 90% of the methane is achievable, and undertook sensitivity analysis on higher rates.

A paper[69] on the impact of landfill on GHG emissions found literature that states a range of landfill gas collection efficiency, such as:

- Pipatti and Wihersaari[70] stated efficiencies between 50% and 100%;
- Oonk and Boom[71] between 24% to 60%; and
- Humer and Lechner[72] between 40% to 60% efficiency.

[65] Pierce, J., LaFountain, L. and Huitric, R., (2005) Landfill gas generation & modeling manual of practice. Solid Waste Association of North America.
[66] Walter, G.R., (2003) Fatal flaws in measuring landfill gas generation rates by empirical well testing. Journal of the Air & Waste Management Association, 53(4), pp.461-468.
[67] El-Fadel, M., Findikakis, A.N. and Leckie, J.O., (1997) Gas simulation models for solid waste landfills. Critical reviews in environmental science and technology, 27(3), pp.237-283.
[68] Smith, A., Brown, K., Ogilvie, S., Rushton, K. and Bates, J., (2001) Waste management options and climate change: Final report to the European Commission. In Waste management options and climate change: final report to the European Commission. European Commission.
[69] Lou, X.F. and Nair, J., (2009) The impact of landfilling and composting on greenhouse gas emissions–a review. Bioresource technology, 100(16), pp.3792-3798.
[70] Pipatti, R. and Wihersaari, M., (1997) Cost-effectiveness of alternative strategies in mitigating the greenhouse impact of waste management in three communities of different size. Mitigation and Adaptation Strategies for Global Change, 2(4), pp.337-358.
[71] Oonk, H. and Boom, T., (1995) Validation of landfill gas formation models. Studies in Environmental Science, 65, pp.597-602.
[72] Humer, M. and Lechner, P., (1999) Alternative approach to the elimination of greenhouse gases from old landfills. Waste Management and Research, 17(6), pp.443-452.

Furthermore, the paper states that laboratory experiments by Bogner and Spokas[73] yielded values ranging 25–50%. This range of recovery efficiency is largely dependent on the waste composition and moisture content. Waste streams with a low organic fraction, e.g. food waste, will result in lower capture efficiency, which others with a higher degradable organic carbon (DOC) such as paper or waste sludge are able to achieve higher capture efficiencies due to the amount of biogas produced[74]).

Knowing the efficiency of biogas capture can have great implications for the GHG mitigation potential. This is illustrated by a study in Phuket, Thailand, where a 50% recovery of landfill gas was recorded which led to a GWP reduction around 58% of the total landfill's GWP[75].

In this context, the maximum collection rate assumed in the NGER Measurement Determination of 75% seems a reasonable value for the practical maximum gas collection percentage. It is worth noting that the Methodology credits for actual, metered destruction above a baseline, as opposed to percentage of collection.

<u>Conclusion 37</u> Key factors affecting the proportion of maximum possible gas collection are depth, width, type of waste, leachate issues, how hot the climate is, how wet the climate is, type of cap, type of lining, how well the landfill is managed in general.
The NGER Measurement Determination assumes that a maximum 75% of gas generated can be collected; actual practice anecdotally and from literature varies from zero (no collection) to under 50% for poorly managed sites to nearly 100% at sites with the most effective collection management.
Note that the percentage of gas collection is not a factor considered in the 2012 or 2015 Methodologies; crediting is on the basis of tons of methane above the baseline amount oxidised.

6.3 Costs of installing and maintaining a landfill gas capture and flare system, including a breakdown of capital costs, installation costs and all ongoing costs.

A high level indicative CAPEX and OPEX assessment for a landfill gas system was performed. The system considered the landfill gas capture, flaring and power generation components. It is noted that landfill sites with power generation capacity will normally have both systems. This is because the excess landfill gas will be flared, whilst using the electricity system at its maximum capacity, or to flare the gas when the engines are unavailable. The below estimates are for indicative comparison and high level uses only. The estimates are based on market research and statistical data from previous projects.

The costs exclude landfill activities (e.g. land purchase, landfill equipment and buildings, fencing, approvals, site or cell development, operations, capping, rehabilitation and aftercare). The costs also exclude the electrical transmission, distribution and associated infrastructure.

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[73] Bogner, J. and Spokas, K., (1995) Carbon storage in landfills. Soils and Global Exchange, edited by R. Lai, et al, pp.67-80.
[74] See for example DCC (Department of Climate Change), 2008. National Greenhouse Accounts Factors. http://www.greenhouse.gov.au/workbook/index.html accessed 25 July 2008.
[75] Liamsanguan, C. and Gheewala, S.H., (2008) The holistic impact of integrated solid waste management on greenhouse gas emissions in Phuket. Journal of Cleaner Production, 16(17), pp.1865-1871.

Furthermore, electrical connection costs (which are required to export electricity to the grid) are a considerable cost. Nevertheless, these costs:

- are site specific; and
- based on the grid infrastructure available in the region / area, the network operator determines the costs associated with the connection.

As such, only the capturing, flaring and power generation system has been considered. Key considerations are summarised in Table 23. Furthermore, Table 24 and Table 25 provide a breakdown of the CAPEX and OPEX estimates respectively. The breakdown of these costs is graphically presented in Figure 22 and Figure 23.

Table 23: Key considerations for CAPEX / OPEX estimates

Consideration	Metric	Qty.	Unit
Landfill gas production	Operating Temperature	25	°C
	Operating Pressure	5	bar
	Gas flow at Standard conditions	988	Sm^3/hr
	Gas flow at Normal conditions	905[76]	Nm^3/hr
Equivalent of waste	Estimate that 80% is MSW waste	1,018,221	Tonnes/year
	Assumed density	170[77]	Sm^3/tonne of waste
Size of landfill	Area	101,822	m^2
	Depth (estimated)	10[78]	m
Potential equivalent of electrical generation		1.78	MWe

[76] This estimate has been primarily based on available gas flow as the key indicator for the calculations.
[77] High level estimate to determine the approximate size (i.e. volume) of landfill required (based on amount of gas flow).
[78] Assumed that the depth of the landfill cell to be 10m for estimation purposes only.

Table 24: Estimated CAPEX costs of installing a landfill gas capture, flare and power generation system

No.	Items	Description	Assumptions	Units	Indicator	Units 2	Nos.	Total AUD[79]
1	CAPEX Cost							$ 4,233,370
1.1	Landfill gas capturing system							$ 599,000
1.1.1	*Wellheads*	*Well system to extract methane beneath landfill cell*	*Each wellhead system covers 60m by 60m area with a depth of 5-10m*	*$/ wellhead*	*$ 2,500*	*Number of wellheads*	*28[80]*	*$ 71,000*
1.1.2	*Gas capture piping headers*	*Piping for capture of gas*	*Piping to connect wellheads to flare system. Assumed pipelines crossed the length twice in total.*	*$ per m*	*$ 600*	*m*	*700[81]*	*$ 420,000*
1.1.3	*Additional Equipment*	*Associated equipment for the landfill gas capturing system (pumps, blowers, etc.)*	*Assumed 15 % of equipment cost*	*%*	*15%*	*%*	*15%*	*$ 108,000*
1.2	Flare System[82]	Flaring methane gas	Assumed USD$200 (AUD$250) per Nm^3/hr landfill gas	$	$ 250	Nm^3/hr LFG	905	$ 226,250
1.3	Electrical Controls	Associated electrical system for the gas capture and flare system	Assumed 10 % of equipment cost	%	10%	%	10%	$ 72,000
1.4	Power Generation	Utilising landfill gas to generate electricity through gas engines	Based on estimated 19 MJ/Sm^3 gross calorific value of landfill methane gas and 35% of gas engine efficiency	$ / kWe	$ 1,800	kWe	1,778[83]	$ 3,201,120
1.5	Engineering	Engineering costs	Includes gas capture, flaring and power generation	%	15%	%	15%[84]	$ 135,000

[79] The estimates are for indicative comparison and high level uses only. These figures are based on market research and statistical data from previous projects. This only includes gas gathering and power generation aspect, landfill capping/process is not included.
[80] Assumes a wellhead is installed for every 60m by 60m of landfill area.
[81] Estimated value, based on professional experience and scalability potential.
[82] Including biogas flare, piping, piping components, blowers, etc.
[83] The power generation component includes gas engines, biogas scrubbing system, gas/exhaust, pipework, associate electrical works (instrumentation and control, high voltage switchgear, switchboard, control systems, transformers, circuit breakers, etc.), general mechanical/civil/earth works.
[84] Engineering includes project management, civil/electrical/environment planning engineering, construction and commissioning supervision, develop cost and construction insurance.

Figure 22 provides a breakdown of the estimated capital expenditure required for the landfill gas capture, flaring and power generation system. Power generation system alone (1.78 MWe considered) represents 76% of the costs.

It is noted that for a landfill gas capture and flaring system, all the costs indicated in the graph (e.g. wellheads, gas capture piping headers, etc.) would be required. The cost breakdown for the gas capture and flare system has been included between brackets.

The gas piping headers represent 10% of the power generation system cost and 41% of the gas capture and flare system. The flare system represents 5% of the power system cost and 22% of the gas capture and flare system.

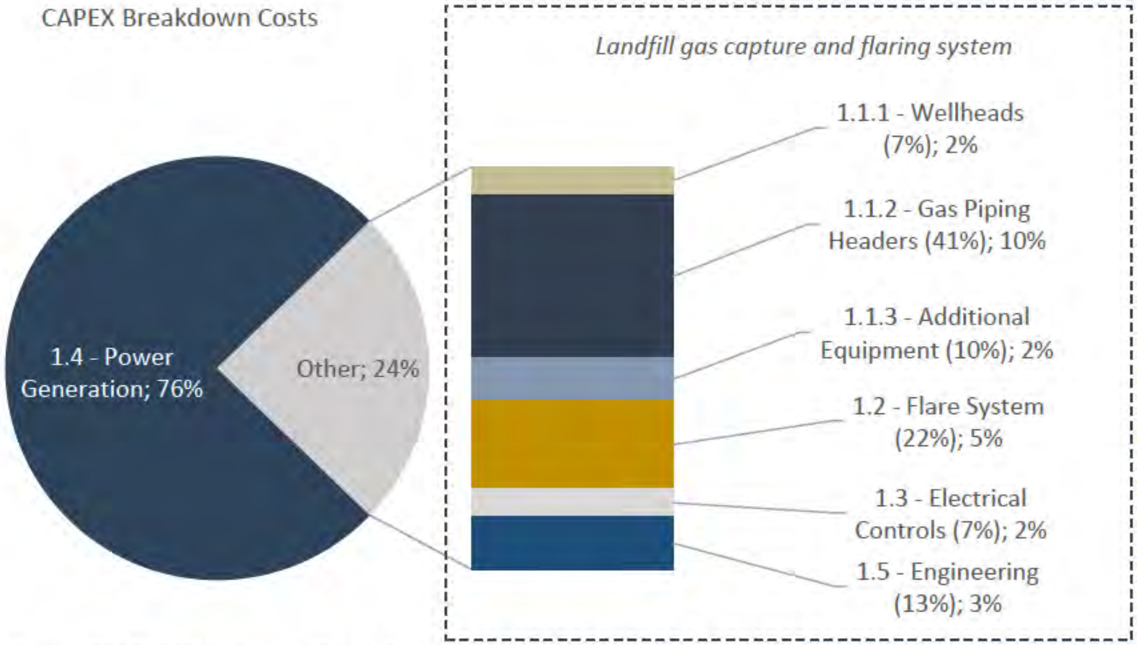

Figure 22: CAPEX Estimates Breakdown – Landfill gas capture, flaring and power generation

The gas piping headers and collection lines costs will dependent on the area of the landfill. This is, the distance to the cell being drained and the depth of the cell[85]. Other costs are:

- Engineering costs, which represent 3% of the power generation system cost and ~10% for the gas capture and flare system (it is noted that the graph shows 13% as it considers other activities).
- Additional equipment (e.g. pumps) represents 2% of the power generation system and 10% of the gas capture and flare system.
- The wellheads and electrical controls each represent 2% of the power generation system and 7% of the costs of the gas capture and flare system.

[85] The gas piping costs are highly variable due to the geometry of the landfill. Also, these factors will influence the gas flow. This is because the product of the area of the landfill times its depth will be approximately related to gas flow, with other variables being:

- the age (older filled cells will generate less volume per year), and
- percentage of waste that is putrescible (waste which is mainly construction waste will have a low gas volume per year).

Table 25: Estimated OPEX costs of maintaining and operating a landfill gas system

No.	Items	Descriptions	Assumptions	Units	Indicator	Units 2	Nos.	Total AUD[86]
2	OPEX Cost per annum							$ 353,150
2.1	Annual O&M of landfill gas capturing system	O&M for overall system	Assumed 10 % of capital cost p.a.	%	7%	%	10%[87]	$ 104,000
2.2	Potential extension of collection lines to new cell	Potential extension factors - wellheads and pipeline	Assumed 10% of wellheads p.a.	%	10%	%	10%[88]	$ 49,100
2.3	Annual O&M for power generation engines	Annual O&M for power generation engines	Assumed $10 per MWh and an availability factor of 90%	per MWh	$ 10	MWh	14,021	$ 140,210
2.4	Annual O&M of wellheads	O&M for the wellheads	Assumed 3 person-days per annum per well	per well	$ 600	no.	28	$ 17,000
2.5	Annual O&M of flare system	O&M for the Flare	Assumed 7% of the flare system CAPEX	%	7%	%	7%	$ 15,840
2.6	Insurance	Insurance for the plant	Assumed 0.5% of the capital cost p.a.	%	0.5%	%	0.5%	$ 22,000
2.7	General Administration	General administration	Assumed 2 person-days per month	daily rate	$ 200	days	24	$ 5,000
3	Engine overhaul		Estimate over the contract period (i.e. yr 1-7)					$ 1,835,480
3.1	Engine rebuild	After 5 to 6 years, the engine needs to undergo a complete refurbishment	Based on major services (overhaul) on the engines that need to be carried out every 16,000 MWh (year 3, 5, 7 and 9). A distributed unit cost is used for this estimate. Estimate based on 24/7 operation with 90% availability factor.	% of CAPEX	Year 3	%	7%	$ 224,100
3.2					Year 5	%	15%	$ 480,200
3.3					Year 7	%	12%	$ 384,200
3.4					Year 9	%	30%	$ 960,400[89]
3.4.1	*Year 9 consideration in contract period (i.e. the life of asset, considering years 1 to 7)*		*Assumed yearly costs are constant, no interest or inflation.*	*Year 9*	*(Years 1 to 7)*	*%*	*30%*	*$ 746,980*

[86] The high-level estimates are for indicative comparison purposes only. These figures are based on market research and statistical data from previous projects. This only includes the gas capture and power generation aspects only. Landfill capping/process is not included.

[87] The O&M cost does not include the landfill capping process. It only covers the gas capturing and flaring system.

[88] An estimate of potential extension of 10% per year was considered.

[89] Not considered in the OPEX Cost.

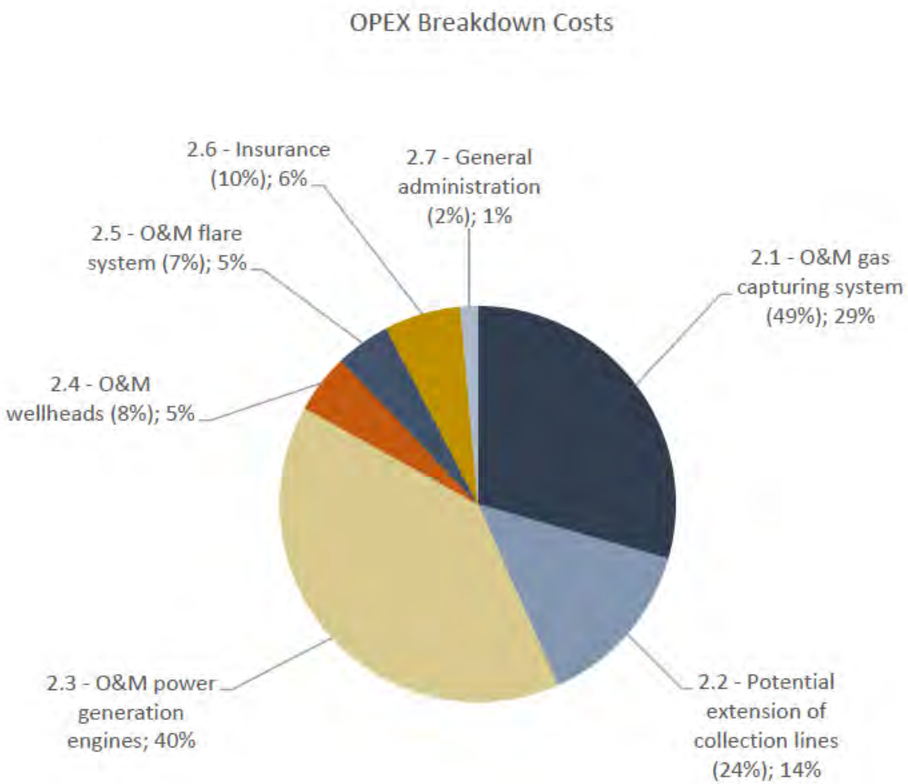

Figure 23: OPEX estimates breakdown - Landfill gas capture, flaring and power generation

Figure 23 provides a breakdown of the ongoing costs associated with a landfill gas capture, flaring and power generation system. The main cost is the operation and maintenance of the power generation engines with 40% of the costs. Other ongoing costs (applicable to both, the capture and flare and power generation systems) are:

- Operation and maintenance of the gas capturing system, representing 29% of the of the power generation system and 49% of the gas capture and flaring system each;
- Potential continual extension of collection lines to new cells, representing 14% of the power generation system and 24% of the gas capture and flaring system;
- Insurance costs, representing 6% of the of the power generation system and 10% of the gas capture and flaring system;
- Operation and maintenance of the flare system and the wellheads, representing 5% of the of the power generation system each and 7% and 8% of the gas capture and flaring system respectively; and
- General administration which would account for approximately 1% and 2% of the ongoing costs.

Note:
Engine rebuild (overhaul) costs (required after 3 years of operation) are not considered in the annual OPEX breakdown costs. They are considered separately as they are not a yearly expense and are provided overleaf.

Figure 24 provides a breakdown of the overhaul costs over the life of asset (i.e. years 1 to 7). These costs are:

- Year 3, corresponding to 7% of the CAPEX, and accounts for 12% of the overhaul costs over the life of asset;
- Year 5, corresponding to 15% of the CAPEX, and accounts for 26% of the overhaul costs over the life of asset;
- Year 7, corresponding to 12% of the CAPEX, and accounts for 12% of the overhaul costs over the life of asset; and
- The overhaul required on year 9, corresponds to 30% of the CAPEX. This expenditure falls out of the considered life of asset, nevertheless, and for representative purposes, the representative costs from year 1 to 7 have been considered. This accounts for 41% of the overhaul costs over the life of asset.

In total, these costs are expected to be AUD$1.84m. These costs are further considered in sections 6.3.1 and 6.3.2.

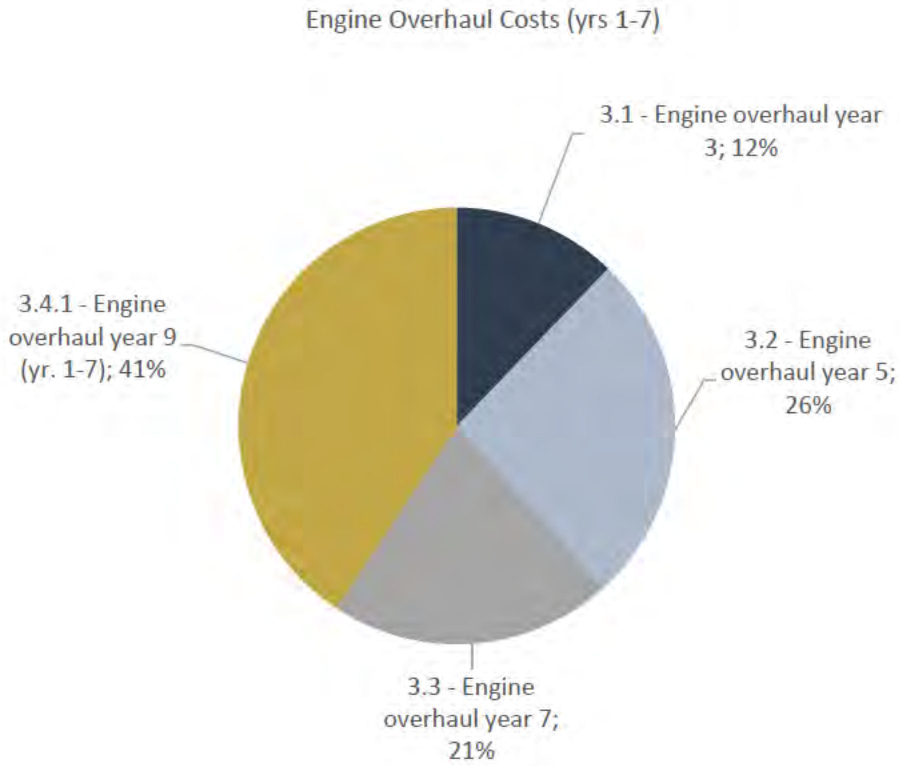

Figure 24: OPEX (engine overhaul) estimates breakdown

6.3.1 Regional Adjustment Consideration

To account for the geographical location variations in costs, a *Regional Adjustment* was determined. The *Regional Adjustment* is based on a building price index[90] and is provided for guidance purposes. The *Regional Adjustment* is provided in Table 26. Additionally, the CAPEX, OPEX and Overhaul costs for the capture, flaring and power generation of the different cities in Australia are provided. The estimates are based on the information provided in Table 24 and Table 25. Sydney costs were considered as the bases of this analysis (i.e. 100%).

Table 26: Regional areas adjustment estimates (AUD$ '000)

Region[91]	Sydney	Adelaide	Brisbane	Canberra	Darwin	Hobart	Melbourne	Perth
Regional Adjustment	**100%**	**88%**	**116%**	**89%**	**110%**	**83%**	**90%**	**108%**
CAPEX ('000)	$4,233	$3,728	$4,914	$3,769	$4,668	$3,501	$3,802	$4,583
OPEX ('000)	$353	$311	$410	$315	$390	$292	$318	$383
Overhaul ('000)	$1,835	$1,617	$2,131	$1,635	$2,024	$1,518	$1,649	$1,987

It is noted that the city of Hobart is the least expensive one and the most expensive one is Brisbane. Brisbane costs are 40% higher than Hobart costs. Pricing of construction costs is highly susceptible to geographical location.

6.3.2 Total Cost of Ownership Consideration

To consider the high-level estimations of the total cost of ownership, a seven-year's life of asset was considered. This timeframe was considered given the ERF's contract period.

For a landfill gas capture, flaring and power generation system as specified in section 6.3, it was estimated that the CAPEX required would total AUD$4.2m. To compare the ongoing costs associated with this system, the OPEX costs over the life of asset were considered. In total, OPEX (operation and maintenance of the system) costs were estimated to be AUD$2.5m. Furthermore, the power generation overhaul costs were considered and were estimated to be AUD$1.4m over the life of asset.

Conversely, similar costs were considered for a gas capture and flaring system only. For this system, the CAPEX was estimated to be AUD$1m and the OPEX over the life of asset AUD$1.5m. It is noted that no overhaul services are required for these systems.

These values are graphically presented in Figure 25. It is noted the total cost of ownership assessment did not consider any required rates of return and time value of money. This is because each project would have different required rates of return depending on their capital structure and risk appetite. However, it is expected that projects would require more than break even on an undiscounted cash flow assessment to be financially viable.

[90] Rawlinsons Quantity Surveyors and Construction Cost Consultants Australia (2016), Rawlinsons - Australian Construction Handbook Edition 34, Rawlinsons Publishing, Perth, WA, Australia, p3.
[91] Cities pricing adjustment is based on price indices for 2015 as indicated in Rawlinsons - Australian Construction Handbook Edition 34 for estimation purposes only.

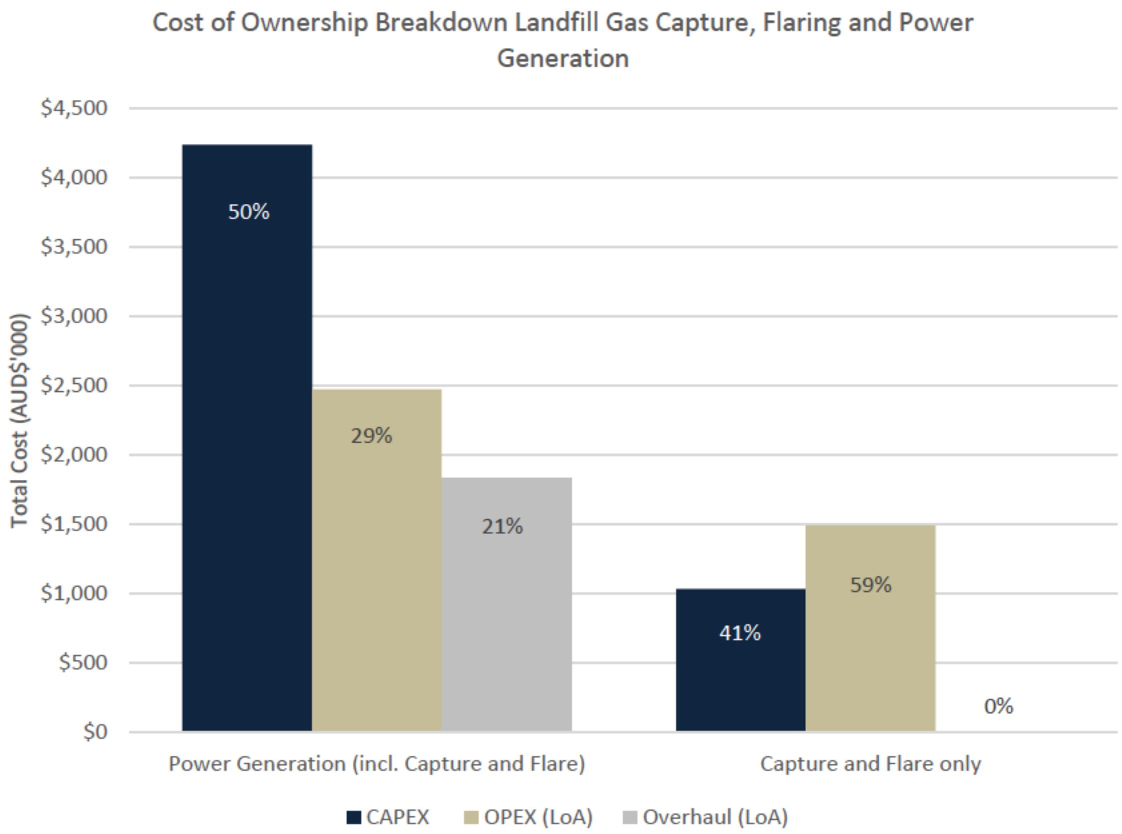

Figure 25: Total Cost of Ownership Breakdown (CAPEX and OPEX)

6.3.2.1 Consideration of electricity generation revenue and ACCUs

The energy generation revenue (i.e. electricity generation and LGCs) and the ACCUs were considered. These are based on estimates provided in section 2.3.2. Table 27 provides a high-level comparison between expenses incurred in a landfill gas power generation project and the potential revenue streams. Furthermore, Table 27 provides two scenarios; with and without ACCUs. In summary and considering the costs over the life of asset if a project:

- has the ACCUs-generating potential, the site will have revenue (approximately after five years of operation for a power generation project and four years for gas capture and flare); and
- does not have the potential to generate ACCUs, then:
  - the power generation project would not have reached parity between the expenses and income at the end of the life of asset; and
  - the gas capture and flare project will not have any income and will all represent costs.

Table 27: Total Cost of Ownership Balance[92]

Summary of expenses / income	Period	Power Generation		Capture & Flare	
		With ACCUs	No ACCUs	With ACCUs	No ACCUs
Total initial costs	One off	-$4,233,370	-$4,233,370	-$1,032,250	-$1,032,250
Total expenses p.a.	Annual	-$353,150	-$353,150	-$212,940	-$212,940
Total services overhaul (annualised)	Annual	-$261,922	-$261,922	$0	$0
Total income p.a.	Annual	$1,395,077	$841,260	$553,817	$0
Life of Asset (7 yr.)					
Total initial costs	One off	-$4,233,370	-$4,233,370	-$1,032,250	-$1,032,250
Total expenses over whole-of-life	LoA	-$2,472,050	-$2,472,050	-$1,490,580	-$1,490,580
Total services overhaul	LoA	-$1,833,450	-$1,833,450	$0	$0
Total income over whole-of-life	LoA	$9,765,550	$5,888,820	$3,876,720	$0
Total Cost of Ownership	**LoA[93]**	**$1,226,680**	**-$2,650,050**	**$1,353,890**	**-$2,522,830**

The following assumptions were made as part of this estimation:

- The total cost of ownership considers seven years of ACCUs, sale of electricity generated and LGCs, noting that they may not all be available from year one.
- The assessment does not consider revenue or levies from the handling or disposal of waste and excludes all costs of the operation of the landfill.
- Total assessment does not consider required rates of return and time value of money (e.g. interests, inflation or discount rates).
- The assessment does not consider variation over time in:
  - Landfill gas and electricity generation;
  - The operation and maintenance costs;
  - Wholesale electricity price; and
  - ACCUs and LGCs.

<u>Conclusion 38</u> For a landfill gas capture, flare and power generation system, over the life of asset considered (seven years), the capital costs represent 50% of the costs and the ongoing costs (e.g. operation and maintenance) represent approximately 30% of the total costs and the power generation overhaul represent approximately 20% of the total costs. For a landfill gas capture and flaring system, these costs would be 41% for the capital costs and 59% for the ongoing costs. This is mainly due to the operation and maintenance requirements of the landfill gas capturing system.

<u>Conclusion 39</u> ACCUs are a strong incentive for power generating projects. In consideration of the life of asset (seven years), the ACCUs contribute to achieving revenue from both the power generation project and the landfill gas capture and flare project. Nevertheless, without the ACCUs and in consideration of the revenue streams from the sale of electricity for applicable projects, these projects may present a loss over the life of asset.

[92] Estimates only – negative quantities represent costs.
[93] Life of asset has been considered to be seven (7) years, in line with the ERF contract period timeframe.

APPENDICES

APPENDIX A: LEGISLATION

Relevant Legislation
NSW
Protection of the Environment Operations Act 1997
Section 3- Objects of Act The objects of this Act are as follows: (a) to protect, restore and enhance the quality of the environment in New South Wales, having regard to the need to maintain ecologically sustainable development, (b) to provide increased opportunities for public involvement and participation in environment protection, (c) to ensure that the community has access to relevant and meaningful information about pollution, (d) to reduce risks to human health and prevent the degradation of the environment by the use of mechanisms that promote the following: i. pollution prevention and cleaner production, ii. the reduction to harmless levels of the discharge of substances likely to cause harm to the environment, a. the elimination of harmful wastes, iii. the reduction in the use of materials and the re-use, recovery or recycling of materials, iv. the making of progressive environmental improvements, including the reduction of pollution at source, v. the monitoring and reporting of environmental quality on a regular basis, (e) to rationalise, simplify and strengthen the regulatory framework for environment protection, (f) to improve the efficiency of administration of the environment protection legislation, (g) to assist in the achievement of the objectives of the Waste Avoidance and Resource Recovery Act 2001.
Section 120- Prohibition of pollution of waters (1) A person who pollutes any waters is guilty of an offence. Note: An offence against subsection (1) committed by a corporation is an offence attracting special executive liability for a director or other person involved in the management of the corporation-see section 169. (2) In this section: "pollute" waters includes cause or permit any waters to be polluted.
Section 124- Operation of plant (other than domestic plant) The occupier of any premises who operates any plant in or on those premises in such a manner as to cause air pollution from those premises is guilty of an offence if the air pollution so caused, or any part of the air pollution so caused, is caused by the occupier's failure: a. to maintain the plant in an efficient condition, or b. to operate the plant in a proper and efficient manner
Section 125- Maintenance work on plant (other than domestic plant) The occupier of any premises who carries out maintenance work on any plant in or on those premises in such a manner as to cause air pollution from those premises is guilty of an offence if the air pollution so caused, or any part of the air pollution so caused, is caused by the occupier's failure to carry out that work in a proper and efficient manner.
Section 126- Dealing with materials 1) The occupier of any premises who deals with materials in or on those premises in such a manner as to cause air pollution from those premises is guilty of an offence if the air pollution so caused, or any part of the air pollution so caused, is caused by the occupier's failure to deal with those materials in a proper and efficient manner. 2) In this section: "deal" with materials means process, handle, move, store or dispose of the materials. "materials" includes raw materials, materials in the process of manufacture, manufactured materials, by-products or waste materials.

127 Proof of causing pollution

To prove that air pollution was caused from premises, within the meaning of sections 124-126, it is sufficient to prove that air pollution was caused on the premises, unless the defendant satisfies the court that the air pollution did not cause air pollution outside the premises.

128 Standards of air impurities not to be exceeded

1) The occupier of any premises must not carry on any activity, or operate any plant, in or on the premises in such a manner as to cause or permit the emission at any point specified in or determined in accordance with the regulations of air impurities in excess of:
    a. the standard of concentration and the rate, or
    b. the standard of concentration or the rate, prescribed by the regulations in respect of any such activity or any such plant. (1A) Subsection (1) applies only to emissions ("point source emissions") released from a chimney, stack, pipe, vent or other similar kind of opening or release point.
2) The occupier of any premises must carry on any activity, or operate any plant, in or on the premises by such practicable means as may be necessary to prevent or minimise air pollution if:
    a. in the case of point source emissions-neither a standard of concentration nor a rate has been prescribed for the emissions for the purposes of subsection (1), or
    b. the emissions are not point source emissions.
3) A person who contravenes this section is guilty of an offence.

Section 129- Emission of odours from premises licensed for scheduled activities

1) The occupier of any premises at which scheduled activities are carried on under the authority conferred by a licence must not cause or permit the emission of any offensive odour from the premises to which the licence applies.
2) It is a defence in proceedings against a person for an offence against this section if the person establishes that:
    a. the emission is identified in the relevant environment protection licence as a potentially offensive odour and the odour was emitted in accordance with the conditions of the licence directed at minimising the odour, or
    b. the only persons affected by the odour were persons engaged in the management or operation of the premises.
3) A person who contravenes this section is guilty of an offence.

VIC

Environment Protection Act 1970

Section 1C- The precautionary principle

(1) If there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.
(2) Decision making should be guided by—
    a) a careful evaluation to avoid serious or irreversible damage to the environment wherever practicable; and
    b) an assessment of the risk-weighted consequences of various options.

Part VI - Clean Air Section 40- Discharges etc. to comply with policy

The discharge or emission of wastes into the atmosphere shall at all times be in accordance with declared State environment protection policy or waste management policy specifying acceptable conditions for discharging or emitting wastes into the atmosphere and shall comply with any standards prescribed therefor under this Act. S. 41 amended by No. 9803 s. 3(a)(b), substituted by No. 10092 s. 14.

Section 41- Pollution of Atmosphere

S. 41(1) amended by No. 20/1988 s. 7(d).

1. A person shall not pollute the atmosphere so that the condition of the atmosphere is so changed as to make or be reasonably expected to make the atmosphere— S. 41(1)(a) amended by No. 10261 s. 18(1).
    a. noxious or poisonous or offensive to the senses of human beings;
    b. harmful or potentially harmful to the health, welfare, safety or property of human beings;
    c. poisonous, harmful or potentially harmful to animals, birds or wildlife;
    d. poisonous, harmful or potentially harmful to plants or other vegetation; or
    e. detrimental to any beneficial use made of the atmosphere.

S. 41(2) amended by Nos 22/1987 s. 22(d), 20/1988 s. 7(e).

2. Without in any way limiting the generality of subsection (1) a person shall be deemed to have polluted the atmosphere in contravention of subsection (1) if—
    a. that person causes or permits to be placed in or so that it may be released into the atmosphere any matter whether solid, liquid or gaseous which—
        i. is prohibited by or under this Act; or
        ii. does not comply with any standard prescribed for that matter; or

S. 41(2)(b) repealed by No. 10261 s. 18(2).
S. 41(2)(b) inserted by No. 30/1989 s. 4(a).

    b. that person causes or permits the discharge or emission of any matter or substance into the atmosphere in contravention of this Act; or
    c. that person uses any chemical substance or fuel the use of which is prohibited by the regulations; or
    d. S. 41(2)(d) inserted by No. 30/1989 s. 4(b).
    e. that person contravenes any regulation dealing with the use of any ozone-depleting substance or the manufacture, assembly, installation, operation, maintenance, removal, sale or disposal of goods, equipment, machinery, or plant containing or using an ozone-depleting substance.

S. 41A inserted by No. 9571
S. 4(1), amended by No. 9758
S. 6, repealed by No. 10092
S. 11(2) (as amended by No. 10160 s. 7(2)).

State Environment Protection Policy (Air Quality Management) No. S240 21/12/2001

Section 11. Ambient Air Quality Objectives

The environmental quality objectives for the purpose of this policy are set out in in Schedule A and Schedule B of State environment protection policy (Ambient Air Quality).

Waste Management Policy (Siting, Design and Management of Landfills) No. S264 12/12/04

Section 14- Works Approval and Licensing

1. Applications for works approvals and licences must comply with the provisions of the policy.
2. All premises that are exempt from either works approvals or licensing must comply with the provisions of the policy.

The Authority will progressively amend existing landfill licences so that they are consistent with the policy.

Section 15- General Requirements

1. Where any provision of the BPEM is inconsistent with the policy, the policy shall prevail.
2. This clause applies to an applicant for or holder of a works approval or licence for a landfill site, unless provided for in Clause 17.
3. An applicant for or holder of a works approval or licence for a landfill site must:
    a. comply with the policy as well as all other relevant State environment protection policies and waste management policies;
    b. meet the objectives of the BPEM; and
    c. meet each required outcome of the BPEM.
4. An applicant for or holder of a works approval or licence for a landfill site should use the suggested measures in the BPEM to demonstrate that subclause (3) will be met.
5. If an applicant for a works approval, licence or licence amendment proposes measures alternative to the suggested measures of the BPEM, the Authority shall not issue the works approval, licence or licence amendment unless the applicant satisfies the Authority that the alternative measures:
    a. meet the requirements of subclause (3); and
    b. provide at least an equivalent environmental outcome to that provided by the suggested measure.

Section 20- Landfill Gas

1. (1) In addition to the obligations contained in Clause 15, the Authority may require a landfill operator to install a landfill gas collection system in existing and/or new landfill cells where:
    a. landfill gas emissions are causing or may cause odours;
    b. landfill gas emissions represent or may represent a hazard; or
    c. it is necessary to reduce greenhouse gas emissions.

QLD
Environmental Protection Act 1994
Section 319- General environmental duty 1. (1) A person must not carry out any activity that causes, or is likely to cause, environmental harm unless the person takes all reasonable and practicable measures to prevent or minimise the harm (the general environmental duty). * Note— * See section 24(3) (Effect of Act on other rights, civil remedies etc.). 2. (2) In deciding the measures required to be taken under subsection (1), regard must be had to, for example— a. the nature of the harm or potential harm; and b. the sensitivity of the receiving environment; and c. the current state of technical knowledge for the activity; and d. the likelihood of successful application of the different measures that might be taken; and e. the financial implications of the different measures as they would relate to the type of activity.
Environmental Protection Regulation 2008
Section 51- Matters to be complied with for environmental management decisions 1. The administering authority must, for making an environmental management decision relating to an environmentally relevant activity, other than a prescribed ERA— a. carry out an environmental objective assessment against the environmental objective and performance outcomes mentioned in schedule 5, part 3, tables 1 and 2; and b. consider the environmental values declared under this regulation; and ba if the activity is to be carried out in a strategic environmental area—consider the impacts of the activity on the environmental attributes for the area under the Regional Planning Interests Act 2014; and c. consider each of the following under any relevant environmental protection policies— i. the management hierarchy; ii. environmental values; iii. quality objectives; iv. the management intent; and d. if a bilateral agreement requires the matters of national environmental significance to be considered—consider those matters. 1A. However, the administering agency is not required to consider the matters mentioned in subsection (1)(d) if the Coordinator-General has, under the State Development Act, section 54Y, issued an environmental approval for the undertaking of all or part of the coordinated project to which the activity relates. 2. For an environmental management decision relating to a prescribed ERA, the administering authority making the decision must— a. carry out an environmental objective assessment against the environmental objective and performance outcomes mentioned in schedule 5, part 3, table 1; and b. consider the matters mentioned in subsection (1)(b), (ba) and (c).
Section 51- Matters to be complied with for environmental management decisions 1. The administering authority must, for making an environmental management decision relating to an environmentally relevant activity, other than a prescribed ERA— a. carry out an environmental objective assessment against the environmental objective and performance outcomes mentioned in schedule 5, part 3, tables 1 and 2; and b. consider the environmental values declared under this regulation; and ba if the activity is to be carried out in a strategic environmental area—consider the impacts of the activity on the environmental attributes for the area under the Regional Planning Interests Act 2014; and c. consider each of the following under any relevant environmental protection policies— i. the management hierarchy; ii. environmental values; iii. quality objectives; iv. the management intent; and

d. if a bilateral agreement requires the matters of national environmental significance to be considered—consider those matters. 1A However, the administering agency is not required to consider the matters mentioned in subsection (1)(d) if the Coordinator-General has, under the State Development Act, section 54Y, issued an environmental approval for the undertaking of all or part of the coordinated project to which the activity relates 2. For an environmental management decision relating to a prescribed ERA, the administering authority making the decision must— a. carry out an environmental objective assessment against the environmental objective and performance outcomes mentioned in schedule 5, part 3, table 1; and b. consider the matters mentioned in subsection (1)(b), (ba) and (c).
SCHEDULE 5, Part 3, Table 1 - Operational Assessment Air Environmental Objective: The activity will be operated in a way that protects the environmental values of air. Performance Outcomes 1. There is no discharge to air of contaminants that may cause an adverse effect on the environment from the operation of the activity 2. All of the following—(a) fugitive emissions of contaminants from storage, handling and processing of materials and transporting materials within the site are prevented or minimised; a. contingency measures will prevent or minimise adverse effects on the environment from unplanned emissions and shut down and start up emissions of contaminants to air; b. releases of contaminants to the atmosphere for dispersion will be managed to prevent or minimise adverse effects on environmental values.
Section 8- Air quality objectives for indicators 1. An air quality objective stated in schedule 1, column 3 for an indicator stated in column 1 and for a period stated in column 4, is prescribed for enhancing or protecting the environmental value stated in column 2 of the schedule for the objective. 2. An air quality objective stated in schedule 1, column 3 must be worked out as an average over the period stated in column 4 for the objective. 3. Despite subsection (1), an environmental value may be enhanced or protected in an area or place if the amount of an indicator in the air environment in the area or place is more than the amount of the air quality objective stated in schedule 1, column 3 for the indicator for not more than the number of days stated in column 5 of the schedule for the indicator. 4. It is intended that the air quality objectives be progressively achieved as part of achieving the purpose of this policy over the long term. 5. This section does not apply to an air emission that may be experienced within a dwelling or workplace if the air emission is released within the dwelling or workplace. 6. In this section— workplace see the Work Health and Safety Act 2011, section 8. Section 9- Management hierarchy for air emissions (1) This section states the management hierarchy for an activity involving air emissions. * Note— See section 51 of the Environmental Protection Regulation 2008. (2) To the extent that it is reasonable to do so, air emissions must be dealt with in the following order of preference— a. firstly—avoid; * Example for paragraph (a)— using technology that avoids air emissions b. secondly—recycle; * Example for paragraph (b)— re-using air emissions in another industrial process c. thirdly—minimise; *Example for paragraph (c)— treating air emissions before disposal d. fourthly—manage. *Example for paragraph (d)— locating a thing that releases air emissions in a suitable area to minimise the impact of the air emissions

Petroleum and Gas (production and safety) Act 2004
Section 72- Restriction on flaring or venting 1. An authority to prospect holder must not flare or vent petroleum in a gaseous state produced under the authority unless the flaring or venting is authorised under this section. 2. (2) Flaring the gas is authorised if it is not commercially or technically feasible to use it— a. commercially under the authority; or b. for an authorised activity for the authority. 3. Venting the gas is authorised if— a. it is not safe to use the gas for a purpose mentioned in subsection (2)(a) or (b) or to flare it; or b. flaring it is not technically practicable.
SA
Environmental Protection Act 1993
Section 25- General environmental duty 1. A person must not undertake an activity that pollutes, or might pollute, the environment unless the person takes all reasonable and practicable measures to prevent or minimise any resulting environmental harm. 2. In determining what measures are required to be taken under subsection (1) regard is to be had, amongst other things, to— a. the nature of the pollution or potential pollution and the sensitivity of the receiving environment; and b. the financial implications of the various measures that might be taken as those implications relate to the class of persons undertaking activities of the same or a similar kind; and c. the current state of technical knowledge and likelihood of successful application of the various measures that might be taken. 3. In any proceedings (civil or criminal), where it is alleged that a person failed to comply with the duty under this section by polluting the environment, it will be a defence— a. if— i. maximum pollution levels were fixed for the particular pollutant and form of pollution concerned by mandatory provisions of an environment protection policy or conditions of an environmental authorisation held by the person, or both; and ii. it is proved that the person did not by so polluting the environment contravene the mandatory provisions or conditions; or b. (b) if— i. an environment protection policy or conditions of an environmental authorisation provided that compliance with specified provisions of the policy or with specified conditions of the authorisation would satisfy the duty under this section in relation to the form of pollution concerned; and ii. it is proved that the person complied with the provisions or with such conditions of an environmental authorisation held by the person. 4. Failure to comply with the duty under this section does not of itself constitute an offence, but— a. compliance with the duty may be enforced by the issuing of an environment protection order; and b. a clean-up order or clean-up authorisation may be issued, or an order may be made by the Environment, Resources and Development Court under Part 11, in respect of non-compliance with the duty; and c. failure to comply with the duty will be taken to be a contravention of this Act for the purposes of section 135

Environment Protection (Air Quality) Policy 2016
Section 15- Taking reasonable and practicable measures to avoid emissions from premises 1. The occupier of premises (other than domestic premises) must ensure that the emission of pollutants to air from the premises is not caused through any failure to take reasonable and practicable measures— a. to maintain fuel-burning equipment, control equipment or any other plant or equipment in an efficient condition; or b. to operate fuel-burning equipment, control equipment or any other plant or equipment in a proper and efficient manner; or c. to carry out maintenance of fuel-burning equipment, control equipment or any other plant or equipment in a proper and efficient manner; or d. to process, handle, move or store goods or materials in or on the premises in a proper and efficient manner. Mandatory provision: Category B offence. In this clause—control equipment means any device that controls, limits, measures, records or indicates air pollution; fuel-burning equipment means any machine, engine, apparatus or structure in which, or in the operation of which, combustible material is burned, but does not include a motor
Section 18- Matters relating to Part 6 of Act 1. In determining any matters under Part 6 of the Act in relation to an activity (including a related development), the Authority must take into account the following matters (to the extent to which they are relevant): a. ground level concentrations—whether the activity has resulted, or may result, in the concentration of a pollutant specified in column 1 of the table in Schedule 2 clause 2 exceeding the maximum concentrations specified in column 4 or 5 for that pollutant over the averaging time specified in column 3 for that pollutant (based on evaluations at ground level using a prescribed testing, assessment, monitoring or modelling methodology for the pollutant and activity); b. odour levels—whether the activity has resulted, or may result, in the number of odour units specified in column 2 of the table in Schedule 3 being exceeded for the number of persons specified in column 1 over a 3 minute averaging time 99.9% of the time (based on evaluations at ground level using a prescribed testing, assessment, monitoring or modelling methodology for the pollutant and activity); c. stack emissions—if the Authority is satisfied that it is not reasonably practicable or feasible to make evaluations in relation to the activity under paragraph (a) or (b)—whether the activity (being an activity specified in column 2 of the table in Schedule 4) has resulted, or may result, in the emission to air of a pollutant specified in column 1 of the table in Schedule 4— i. at a level exceeding that specified for the pollutant in column 3; or ii. in contravention of a requirement (if any) specified for the pollutant in column 4, (based on evaluations at the stack using a prescribed testing, assessment, monitoring or modelling methodology for the pollutant and activity); d. evaluation distances—whether the assessment requirements set out in the document entitled Evaluation Distances for Effective Air Quality and Noise Management 2016 prepared by the Authority give rise to requirements for separation distances between the activity and other premises; e. localised air quality objectives—any localised air quality objectives (within the meaning of clause 14) that apply in relation to the activity; f. any other kind of air pollution—whether the activity has resulted or may result in the pollution of the air in any other manner; g. requirements to be imposed on all relevant persons—the requirements that should, in the event of an environmental authorisation being granted, be imposed on all relevant persons for the purposes of preventing or minimising the pollution of the air or its harmful effects. 2. In this clause— prescribed testing, assessment, monitoring or modelling methodology, for a pollutant or activity, means—

a. (a) a testing, assessment, monitoring or modelling methodology set out for the pollutant or activity in—
   i. Ambient Air Quality Assessment 2016 prepared by the Authority; or
   ii. Emission Testing Methodology for Air Pollution 2012 prepared by the Authority; or
   iii. some other testing, assessment, monitoring or modelling methodology approved by the Authority for the pollutant or activity.

WA

Environmental Protection Act 1986

Section 4A - Object and principles of Act

The object of this Act is to protect the environment of the State, having regard to the following principles —

1. The precautionary principle: Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation. In the application of the precautionary principle, decisions should be guided by —
   a) careful evaluation to avoid, where practicable, serious or irreversible damage to the environment; and
   b) an assessment of the risk-weighted consequences of various options.
2. The principle of intergenerational equity: The present generation should ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of future generations.
3. The principle of the conservation of biological diversity and ecological integrity. Conservation of biological diversity and ecological integrity should be a fundamental consideration.
4. Principles relating to improved valuation, pricing and incentive mechanisms
   a) Environmental factors should be included in the valuation of assets and services.
   b) The polluter pays principle — those who generate pollution and waste should bear the cost of containment, avoidance or abatement.
   c) The users of goods and services should pay prices based on the full life cycle costs of providing goods and services, including the use of natural resources and assets and the ultimate disposal of any wastes.
   d) Environmental goals, having been established, should be pursued in the most cost effective way, by establishing incentive structures, including market mechanisms, which enable those best placed to maximise benefits and/or minimise costs to develop their own solutions and responses to environmental problems.
5. The principle of waste minimisation. All reasonable and practicable measures should be taken to minimise the generation of waste and its discharge into the environment.

NT

Waste Management and Pollution Control Act

Section 12- General environmental duty

1. A person who:
   a. conducts an activity that causes or is likely to cause pollution resulting in environmental harm or that generates or is likely to generate waste; or
   b. performs an action that causes or is likely to cause pollution resulting in environmental harm or that generates or is likely to generate waste, must take all measures that are reasonable and practicable to:
   c. prevent or minimise the pollution or environmental harm; and
   d. reduce the amount of the waste.

TAS

Environmental Management and Pollution Control Act 1994

23A. General environmental duty

1. A person must take such steps as are practicable or reasonable to prevent or minimise environmental harm or environmental nuisance caused, or likely to be caused, by an activity conducted by that person.
2. In determining whether a person has complied with the general environmental duty, regard must be had to all the circumstances of the conduct of the activity, including but not limited to –
   a. the nature of the harm or nuisance or likely harm or nuisance; and

b. the sensitivity of the environment into which a pollutant is discharged, emitted or deposited; and
c. the current state of technical knowledge for the activity; and
d. the likelihood and degree of success in preventing or minimising the harm or nuisance of each of the measures that might be taken; and
e. the financial implications of taking each of those measures.

3. Failure to comply with subsection (1) does not itself constitute an offence or give rise to a civil right or remedy, but if a person has failed to comply with that subsection an environment protection notice may be issued to that person.

Where a person, in relation to an environmentally relevant activity, takes all measures specified, in a code of practice made and approved in accordance with the regulations, as meeting the requirements for compliance with the general environmental duty in respect of the activity, the person is taken to have complied with the general environmental duty in respect of the activity.

Environment Protection Policy (Air Quality) 2004

Part 3 - Environmental Values and Standards

Environmental values

Section 6-

1. Environmental values are the values or uses of the environment that are to be protected.
2. The environmental values to be protected under this Policy are –
    a. the life, health and well-being of humans at present and in the future;
    b. the life, health and well-being of other forms of life, including the present and future health, wellbeing and integrity of ecosystems and ecological processes;
    c. visual amenity; and
    d. the useful life and aesthetic appearance of buildings, structures, property and materials.

ACT

Environmental Protection Act 1997

22 General environmental duty

1. A person must take the steps that are practicable and reasonable to prevent or minimise environmental harm or environmental nuisance caused, or likely to be caused, by an activity conducted by that person.
2. In deciding whether a person has complied with the general environmental duty, regard must first be had, and greater weight must be given, to the risk of the environmental harm or environmental nuisance involved in conducting the activity, and, in addition, regard must then be had to—
    a. the nature and sensitivity of the receiving environment; and
    b. the current state of technical knowledge for the activity; and
    c. the financial implications of taking the steps mentioned in subsection (1); and
    d. the likelihood and degree of success in preventing or minimising the environmental harm or environmental nuisance of each of the steps that might be taken; and
    e. other circumstances relevant to the conduct of the activity.
3. Subject to section 125, section 143 and section 160, failure to comply with the general environmental duty does not of itself—
    a. give rise to a civil right or remedy; or
    b. constitute an offence; or
    c. constitute grounds for action under this Act.

APPENDIX B: GUIDELINES

Guidelines provide information on how landfills should operate to meet acceptable, good or best practice. These may represent a reference for interpreting what compliance with legislative requirements means in the context of a landfill site.
NSW
NSW EPA, Environmental Guidelines: Solid waste guidelines, Second edition, 2016
These guidelines provide guidance for the environmental management of landfills in NSW by specifying a series of 'Minimum Standards'. They involve a mix of design and construction techniques, effective site operations, monitoring and reporting protocols, and post-closure management. The NSW Environment Protection Authority (EPA) will use these guidelines to assess applications for new or varied landfill licences under the Protection of the Environment Operations Act 1997 and to assess issues that arise during the operational and post-closure periods of landfills. The minimum standards in these guidelines apply to general solid waste and restricted solid waste landfills. There are some additional (higher) standards for restricted solid waste landfills, recognising the more highly contaminated nature of those wastes. The minimum standards in these guidelines reflect the following broad goals for landfilling in NSW: ▪ landfills should be sited, designed, constructed and operated to cause minimum impacts to the environment, human health and amenity ▪ the waste mass should be stabilised, the site progressively rehabilitated, and the land returned to productive use as soon as practicable. ▪ wherever feasible, resources should be extracted from the waste and beneficially reused ▪ adequate data and other information should be available about any impacts from the site, and remedial strategies should be put in place when necessary ▪ all stakeholders should have confidence that appropriately qualified and experienced personnel are involved in the planning, design and construction of landfills to high standards. These guidelines combine and replace the existing documents Environmental Guidelines: Solid Waste Landfills (NSW EPA, 1996) and the Draft Environmental Guidelines for Industrial Waste Landfilling (NSW EPA, 1998). The principal legislation governing waste management and landfill disposal of waste in NSW is the Protection of the *Environment Operations Act 1997*.
VIC
VIC EPA, Best Practice Environmental Management: Siting, design, operation and rehabilitation of landfills, 2015
This document is intended to provide guidance for landfill operators to meet the environment protection objectives of the regulatory framework. This is achieved by establishing a hierarchy of objectives, required outcomes and suggested measures for each section of the document. The objectives and required outcomes are derived directly from legislation and must be achieved. The suggested measures are provided to assist with achievement of the objectives and required outcomes. Where a landfill operator believes that an alternative to the suggested measures will achieve the objectives and required outcomes, the operator will need to provide independently assessed evidence supporting the proposed measure with their submission to EPA. Alternatively, if the suggested measures contained in this document are not likely to achieve the objectives and required outcomes, then EPA may require alternative measures to those suggested, which EPA will support with an assessment of why the alternative measures are required. This is most likely to occur where a landfill is located or proposed in a particularly sensitive environment.

QLD
QLD Department of Environment and Heritage Protection, Guideline: Landfill siting, design, operation and rehabilitation, 2013
The department expects the environmental outcomes detailed in the guideline to be achieved by landfill operators to ensure the protection of the environment from all waste disposal activities regardless of size, threshold or location. By moving to a risk based approach, as described later in the document, this guideline recognises that existing and proposed landfill sites are each subject to a different suite of individual site-specific circumstances. The environmental outcomes required by the department are fixed and must be met; however the way in which the outcomes are achieved is not fixed. The department is also committed to introducing elements of best practice environmental management to existing landfilling operations (where they can reasonably be introduced) with the objective of raising the standard and reducing the risk of pollution. Best practice environmental management is defined in Section 21 of the Environmental Protection Act 1994 (EP Act), as '...the management of the activity to achieve an ongoing minimisation of the activity's environmental harm through cost-effective measures assessed against the measures currently used nationally and internationally'. The department will work with landfill operators wherever possible, or use the enforcement tools available under the EP Act if necessary, to introduce best practice environmental management and ultimately increase the level of environmental protection.
SA
SA EPA Guidelines, Environmental management of landfill activities (municipal solid waste and commercial and industrial general waste), January 2007
Development and operation of landfill facilities in South Australia are activities of environmental significance and these activities must be carried out in accordance with the Environment Protection Act 1993 (the EP Act). This guideline is intended to provide guidance to landfill operators, developers, planning authorities and regulatory bodies on the site selection, development, design, construction, operation, closure and post-closure management of municipal solid waste, and commercial and industrial (C&I) general waste landfill facilities so that they can comply with the EP Act. An SA EPA Guideline provides guidance to industry or the community concerning specific issues, and: ▪ is primarily advisory ▪ includes technical information and recommends ways of undertaking an activity: ideas for 'how to' ▪ prescribes an environmental outcome, but is not normally prescriptive about the mechanisms by which an outcome would be achieved, as it seeks to encourage rather than stifle innovation ▪ is intended for internal and external use ▪ is not directly enforceable; however, it may be used to help the EPA interpret the general environment duty for a particular situation, and may be enforced through issuing an EPO, a condition of licence, or a condition of a development approval.
WA
WA Department of Environment Regulation, Environmental Standard: Metropolitan landfills (due for release 2017)
Environmental Standards set out the required levels of environmental performance for regulated activities based on the hierarchy of preventing, controlling, abating and mitigating pollution and environmental harm. DER's Guidance Statement: Regulatory Principles provides high-level principles of good regulatory practice that guide the exercise of DER's environmental regulation functions. This Guidance Statement builds on those regulatory principles by providing greater detail on how DER will apply Environmental Standards to applications for, and conditions on, works approvals and licences. Environmental Standards are part of DER's hierarchy of instruments governing environmental regulation and apply to a range of DER's regulatory functions. This Guidance Statement should be read together with DER's Guidance Statement: Regulatory Principles which contains information on the application of Environmental Standards.

NT
NT EPA Guidelines for siting, design and management of Solid Waste Disposal Sites, in the Northern Territory, 2013
These guidelines have been written to provide guidance to landfill operators, developers, planning authorities and regulatory bodies on the site selection, development, design, construction, operation, closure and post-closure management of municipal solid waste, and commercial and industrial (C&I) general waste landfill facilities so that they can comply with the Waste Management and Pollution Control Act. The purpose of these Guidelines is to provide a consistent and environmentally responsible approach to managing landfills in the Northern Territory. This guide should be used for the planning of environmental approvals and licensing for new landfill sites and expansion of existing landfill sites. It also applies, where appropriate, to existing landfill sites.
TAS
Department of Primary Industries, Water and Environment, Landfill Sustainability Guide, 2004
The Sustainability Guide is designed to help landfill operators achieve good environmental performance. While the Sustainability Guide itself is not a legally enforceable document, permit conditions (which are legally enforceable) are likely to be derived from the acceptable standards and recommendations described within the Sustainability Guide.
ACT
No guidelines available

APPENDIX C: LICENCES

NSW
Protection of the Environment Operations Act 1997
NSW Environmental Protection Authority
The EPA assesses the site-specific risks posed by each licensed activity, in terms of the risks relating to the day-to-day operations as well as the pollution incident risk at the premises. The prior environmental management performance of the licence holder at the premises will also be used to determine the level of risk. The EPA's risk-based licensing system aims to ensure that all environment protection licence holders receive an appropriate level of regulation based on the level of risk that they pose to human health and the environment. Licences may reference: ▪ *NSW EPA, Environmental Guidelines: Solid waste landfills, Second edition, 2016* ▪ *NSW EPA, Environmental Guidelines: Solid waste landfills, 1996* ▪ Site specific landfill environmental management plans (LEMPs) ▪ Site specific pollution limits Separate to the requirements of the licence, general obligations of licensees are set out in the *Protection of the Environment Operations Act 1997* and the Regulations made under the Act. These include obligations to: ▪ ensure persons associated with you comply with this licence, as set out in section 64 of the Act; ▪ control the pollution of waters and the pollution of air (see for example sections 120 - 132 of the Act); ▪ report incidents causing or threatening material environmental harm to the environment, as set out in Part 5.7 of the Act.
VIC
Environment Protection Act 1970
VIC Environmental Protection Authority
EPA requirements for environmental management of landfill operations have changed as part of the licence reform program. These changes have led to landfill licences being less prescriptive and require licence-holders to better identify and manage the environmental impacts of their landfill operations. This shift in responsibility has also increased the requirement for environmental assessments and audits of landfill management activities by environmental auditors appointed under the *Environment Protection Act 197* (environmental auditors). Licences contain standard conditions that aim to control the operation of the premises so that there is no adverse effect on the environment. These conditions address areas such as waste acceptance and treatment, air and water discharges, and noise and odour. The *Environment Protection Act 1970* specifies penalties for breach of licence conditions and for operating a site without a licence. Generally, licence requirements reference the VIC EPA's *Best Practice Environmental Management: Siting, design, operation and rehabilitation of landfills, 2015.*
QLD
Environmentally Relevant Activity (ERA 60) - Environment Protection Act 1994
QLD Department of Infrastructure, Local Government and Planning
All activities that meet the definition for ERA 60 in Schedule 2 of the *Environmental Protection Regulation 2008* (EP Reg), will, regardless of threshold, require an environmental authority to be obtained under the *Environment Protection Act 1994* prior to being able to operate the activity. ERA 60 outlines the model operating conditions provide a framework of conditions that will apply to landfill operations across the State of Queensland. In giving approval under the EP Act for *ERA 60—Waste disposal activities*, the administering authority must address the regulatory requirements set out in the Environmental Protection Regulation 2008 and the standard criteria contained in the EP Act. The administering authority will give consideration to these regulatory requirements in the context of specific information about the environmental impacts of a particular project provided through application documentation for an environmental authority. Conditions in your environmental authority will generally state what is and what is not permitted as part of the activity. They will relate to the operation of the activity and also cover rehabilitation requirements. Generally, the licences reference conditions set out in *VIC EPA Best practice environmental management: Siting, design, operation and rehabilitation of landfills, 2015.*
SA

Environment Protection Act 1993
SA Environmental Protection Authority
The EPA imposes conditions through a licence to regulate activities that have the potential to harm the environment. Any person or company undertaking these types of activities may need an EPA licence, as required by the *Environment Protection Act 1993*. The term of a licence is generally five years, but can vary from one to 10 years based on the EPA's assessment of the risk or duration of the activity. A licence is an enforceable agreement between the EPA and the licensee that sets out the minimum acceptable environmental standards to which the licensee must perform. The EPA considers how high the environmental risk is likely to be from the licensed activities, when setting conditions of the licence. Subsequently, environmental licences are unique and may be developed to focus on any or all of the following objectives: ▪ documentation of the requirements of a licensee under existing regulations ▪ facilitating the attainment of environmental performance standards of the licensee ▪ facilitating the alignment of the behaviour of the licensee with the core environmental objectives required under the Environment Protection Act 1993 and related policies. The Act also requires that all reasonable and practical measures are taken to protect, restore and enhance the quality of the environment, including requiring persons engaged in polluting activities to progressively make environmental improvements. This will affect how the minimum acceptable standards are determined and reflected in licences.
WA
Environmental Protection Act 1986
WA Department of Regulation
The Department of Environment Regulation has responsibility under Part V of the *Environmental Protection Act 1986* for the licensing and registration of prescribed premises, the issuing of works approvals and administration of a range of regulations. DER also monitors and audits compliance with works approvals, licence conditions and regulations, take enforcement actions as appropriate, and develops and implements Departmental licensing and industry regulation policy.
NT
Environment Protection Licence - Waste Management and Pollution Control Act
NT Environment Protection Authority
An Environment Protection Licence is required for Schedule 2 activities under the *Waste Management and Pollution Control Act*. Environment Protection Licences are generally associated with operational activity. Pursuant to Section 30, Part 2 of Schedule 2 of the Waste Management and Pollution Control Act a landfill servicing the waste disposal requirements of more than 1000 persons1 cannot be operated without a Licence. Licence is not required to operate a landfill that services a permanent population of less than 1000 persons that only accepts municipal solid waste (MSW). However facilities that service less than 1000 persons can still use the guide as a tool for effective waste management.
TAS
Environmental Management and Pollution Control Act 1994
TAS Environment Protection Authority
Landfills that receive 100 tonnes or more of solid waste per annum are determined to be a "level 2 activity" under Schedule 2 of the EMPCA. Consequently, regulatory approval is required from the Board for the design and operation of these landfills. To gain approval, proponents must demonstrate that the acceptable standards outlined in the *Landfill Sustainability Guide 2004* will be achieved. Proponents may select the best mix of controls for site development and management to achieve the required outcome and document these in the Development Proposal and Environmental Management Plan (DP&EMP). In general, a DP&EMP will consider the impact of the development and demonstrate the means to mitigate these impacts, and will address issues including (but not limited to) those described within the Sustainability Guide.
ACT
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APPENDIX D: EXCEEDANCE RESPONSES

NSW
Guidelines Requirements
Surface Emissions Monitoring
The threshold level for further investigation and corrective action is 500 parts per million (volume/volume) of methane at any point on the landfill surface for intermediate and finally-capped areas. If methane is detected at levels above 500 parts per million, investigation and corrective actions can include: ▪ repair or replacement of the cover material ▪ flux (emissions) monitoring to quantify emission rates and help identify the extent of gas loss (surface scans give a concentration, not a flow rate) ▪ installation of sub-surface monitoring wells (if not already installed) to gauge the extent of any lateral migration of gas ▪ adjustment or installation of landfill gas controls to extract and treat gas.
Subsurface Monitoring
The threshold levels for further investigation and corrective action are detection of methane at concentrations above 1% (volume/volume) and carbon dioxide at concentrations of 1.5% (volume/volume) above established natural background levels. If methane is detected at concentrations above 1% (volume/volume), the occupier must notify the EPA promptly. Within 14 days of this notification, the occupier must submit a plan to the EPA for further investigation and/or remediation of the elevated gas levels. Depending on the circumstances, this plan may include one or more of the following measures: ▪ an increase in monitoring frequency and/or the installation of additional monitoring wells ▪ volumetric/gas flow determinations to assess the significance of gas generation rates and the potential scale of off-site gas migration ▪ gas accumulation monitoring in enclosed structures located nearby ▪ a revised landfill gas risk assessment, addressing the source, potential gas migration pathways and potential receptors ▪ notifications to potentially affected persons ▪ installation of landfill gas controls at the source and/or receptors.
Gas accumulation in enclosed structures
The threshold level for further investigation and corrective action is detection of methane at concentrations above 1% (volume/volume). If methane is detected at concentrations above 1% (volume/volume), the occupier must notify the EPA within 24 h. Within 14 days of this notification, the occupier must submit a plan to the EPA for further investigation and/or remediation of the elevated gas levels. Depending on the circumstances, this plan may include: ▪ daily testing of the building or enclosed structure until ventilation or other measures have been put in place to eliminate the methane build-up ▪ installation or adjustment of source and receptor landfill gas controls ▪ further sub-surface monitoring to delineate any potential migration of landfill gas.
Additional Licence Requirement
R2.1 Notifications must be made by telephoning the Environment Line service on 131 555. Note: The licensee or its employees must notify all relevant authorities of incidents causing or threatening material harm to the environment immediately after the person becomes aware of the incident in accordance with the requirements of Part 5.7 of the Act. R2.2 The licensee must provide written details of the notification to the EPA within 7 days of the date on which the incident occurred.

VIC
BPEM Guidelines Requirements
The action levels for landfill gas at different monitoring locations are set out in Table 6.4 of the EPA Best Practice Environmental Management Guidelines. When these action levels are exceeded, the landfill operator must notify EPA within 24 hours. The notification is also to advise what action will be taken to address the matter, what further testing will be done to demonstrate effectiveness of the works, anticipated time frame for the works, or when a detailed landfill gas remediation action plan (LFGRAP) would be prepared and forwarded to EPA. EPA need not be advised of an excursion above an action level where only an onsite location was affected and the matter is rectified within 24 hours. Where an action level has been exceeded at an offsite location, or the result indicates that an action level would be exceeded offsite, then the landfill operator must prepare a landfill gas remediation action plan (LFGRAP). When buildings offsite are or may be impacted by landfill gas, the LFGRAP must be verified by an environmental auditor as taking all practicable measures in the circumstances to reduce the risks from the landfill gas to acceptable levels. Notwithstanding the requirement for auditor verification, the draft LFGRAP is to be forwarded to the EPA as soon as practicable. Auditor verification of the draft LFGRAP is not required prior to its submission to the EPA. The following landfill gas levels inside a building, if confirmed, should trigger advised relocation from the building: ▪ 1% v/v methane. The emergency services need to be advised immediately for action consistent with Victoria's emergency management arrangements. EPA and other relevant authorities should also be advised.
Additional Licence Requirement
Condition LI_G2 You must immediately notify EPA of non-compliance with any condition of this licence.
QLD
ERA 60
The duty to notify requires a person to give notice where serious or material environmental harm is caused or there is a risk of such harm and that harm is not authorised by the administering authority. If methane gas levels exceeding methane standards referred to in condition A3 (action criteria within ERA 60) are detected, all necessary steps must immediately be taken to ensure protection of human health.
SA
Licence Requirement
The Licensee must report to the EPA (on EPA emergency phone number 1800 100 833) all incidents causing or threatening serious or material environmental harm, upon becoming aware of the incident, in accordance with section 83 of the Act. In the event that the primary emergency phone number is out of order, the Licensee should phone (08) 8204 2004
WA
General Licence Requirement
2.1.1 The Licensee shall record and investigate the exceedance of any descriptive or numerical limit or target specified in any part of section 2 of this Licence.
WA
Guidelines
Subsurface monitoring
As a minimum, monitoring of each probe should be carried out six monthly until probe gas concentrations have stabilised below 1% by volume methane and 1.5% by volume carbon dioxide. In the absence of buildings within 250 metres of the landfill boundary, the USEPA guidance value, above which gas control is required, is 5% methane in a boundary probe. More frequent monitoring will be required where gas is found in close proximity to properties. In the case of residential properties, permanent gas monitoring equipment may be necessary.

Building monitoring
Where a building is determined to be at potential risk, based on probe monitoring results or other monitoring information, the building should be regularly monitored to check for the presence of landfill gas. During the monitoring, a portable gas sampler should be used to measure methane and carbon dioxide concentrations in all voids and areas in the basement and/or ground floor and wall cavities of the building. If possible, measurements should be made in each location before allowing ventilation to occur (e.g. measure under a door before opening). If landfill gas is detected, the cause should be remedied as soon as practically possible. Generally, if methane in excess of the 10% lower explosive limit is detected, gas control measures will be required. If concentrations are found to exceed 1% by volume methane or 1.5% by volume carbon dioxide, the building should be evacuated, all ignition sources (including electricity) switched off, and remedial work carried out as soon as possible under an approved health and safety plan prior to reoccupation.
TAS
Guidelines Requirements
Further assessment and remediation should be undertaken if subsurface concentrations exceed 1.25% (v/v) or if surface concentrations exceed 500ppm (v/v).
ACT
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APPENDIX E: REFERENCES

References have been provided throughout the document. A consolidated list of the references is provided in this Appendix.

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APPENDIX F: CALCULATIONS SUMMARY

Summary of calculations for section 2.3.2.

2017 estimated data

Details	Data	Units	Source
CH_4 global warming potential	25		NGER Measurement Determination
Energy content of methane	0.038	GJ/m^3	S1, NGER (Measurement) Determination, 2016
Density of methane at standard temperature and pressure	0.00068	t/m^3	NGER (Measurement) Determination, 2016, 5.4
Energy content of methane	55.57	GJ/t	
Average energy conversion efficiency, landfill gas system	33%		Blue Environment estimate
Conversion factor, GJ to GWh	0.00028		By definition
Proportion of captured methane used for energy recovery	98%		Blue Environment estimate based on experience with NGER data and typical downtime of electricity engines
CH_4:C atomic ratio	1.33		
Emissions destroyed by flare	98%		NGER Measurement Determination
Baseline (regulatory proportion)	30%		
Value per ACCU	$ 11	AUD$	Estimate
Value per MWh electricity + LGC	$ 60	(MWh equiv.)	Assume electricity and LGCs 'bundled' together at $60 based on: Origin PPA $50-$60 http://reneweconomy.com.au/origin-stuns-industry-with-record-low-price-for-530mw-wind-farm-70946/ AGL Silverton windfarm at $65 http://reneweconomy.com.au/agls-new-200mw-silverton-wind-farm-to-cost-just-65mwh-94146/ and assume half each so assume ▪ electricity $30/MWh ▪ LGCs $30/MWh

Methane collected	1,000,000	m^3	
	678	t	
CO_2-e emissions equivalent	16,960	t CO_2-e	
Emissions avoided	16,621	t CO_2-e	
Emissions creditable	11,635	t CO_2-e	
Energy content	37,700	GJ	
Energy generated	12,192	GJ	
	3.39	GWh	
Value of ACCUs	**$127,980**	AUD$	39%
Value of electricity generated + LGCs	**$ 203,203**	AUD$	61%

2013 estimated data

Details	Data	Units	Source
CH_4 global warming potential	25		NGER Measurement Determination
Energy content of methane	0.038	GJ/m³	S1, NGER (Measurement) Determination, 2016
Density of methane at standard temperature and pressure	0.00068	t/m³	NGER (Measurement) Determination, 2016, 5.4
Energy content of methane	55.57	GJ/t	
Average energy conversion efficiency, landfill gas system	33%		Blue Environment estimate
Conversion factor, GJ to GWh	0.00028		By definition
Proportion of captured methane used for energy recovery	98%		Blue Environment estimate based on experience with NGER data and typical downtime of electricity engines
CH_4:C atomic ratio	1.33		
Emissions destroyed by flare	98%		NGER Measurement Determination
Baseline (regulatory proportion)	30%		
Value per ACCU	$ 20	AUD$	Estimate, during period when compliance ACCUs fixed price at $23.00 then $24.15
Value per MWh electricity + LGC	$ 120	(MWh equiv.)	Estimated using Figure 5.

Methane collected	1,000,000	m³	
	678	t	
CO_2-e emissions equivalent	16,960	t CO_2-e	
Emissions avoided	16,621	t CO_2-e	
Emissions creditable	11,635	t CO_2-e	
Energy content	37,700	GJ	
Energy generated	12,192	GJ	
	3.39	GWh	
Value of ACCUs	**$232,691**	AUD$	36%
Value of electricity generated + LGCs	**$ 406,406**	AUD$	64%

Scenario 1 – High Bundle – Low ACCU

Details	Data	Units	Source
CH_4 global warming potential	25		NGER Measurement Determination
Energy content of methane	0.038	GJ/m^3	S1, NGER (Measurement) Determination, 2016
Density of methane at standard temperature and pressure	0.00068	t/m^3	NGER (Measurement) Determination, 2016, 5.4
Energy content of methane	55.57	GJ/t	
Average energy conversion efficiency, landfill gas system	33%		Blue Environment estimate
Conversion factor, GJ to GWh	0.00028		By definition
Proportion of captured methane used for energy recovery	98%		Blue Environment estimate based on experience with NGER data and typical downtime of electricity engines
CH_4:C atomic ratio	1.33		
Emissions destroyed by flare	98%		NGER Measurement Determination
Baseline (regulatory proportion)	30%		
Value per ACCU	$ 8	AUD$	Estimate for the Scenario
Value per MWh electricity + LGC	$ 100	(MWh equiv.)	Estimated mid-point in FY14 bar in Figure 5.

Methane collected	1,000,000	m^3	
	678	t	
CO_2-e emissions equivalent	16,960	t CO_2-e	
Emissions avoided	16,621	t CO_2-e	
Emissions creditable	11,635	t CO_2-e	
Energy content	37,700	GJ	
Energy generated	12,192	GJ	
	3.39	GWh	
Value of ACCUs	**$93,076**	AUD$	22%
Value of electricity generated + LGCs	**$338,672**	AUD$	78%

APPENDIX G: VICTORIA LANDFILL LICENCE COMPLIANCE (L5)

Summary of the Victorian landfill compliance with L5 (*You must prevent emissions of landfill gas from exceeding the investigation levels specified in Best Practice Environmental Management, Siting, Design, Operation and Rehabilitation of Landfills (EPA Publication 788)*).

No	Licence No	Licence Name	2013	2014	2015	2016
1	12281	COLAC-OTWAY SHIRE COUNCIL	Yes	Yes	Yes	Yes
2	9089	BAXTER BUSINESS PTY LTD	No	No	No	No
3	11646	ALPINE SHIRE COUNCIL	No results			
4	11650	YARRA RANGES SHIRE COUNCIL	No results			
5	11684	RIVERLEE CARUSO EPPING PTY LTD	NA	NA	No	No
6	11758	B.T.Q GROUP PTY LTD	Yes	Yes	Yes	Yes
7	11789	CALDER PARK RACEWAY PTY LTD	Yes	Yes	Yes	Yes
8	11818	GLEN LANDFILL PTY LTD	Yes	No	No	Yes
9	11848	GEELONG LANDFILL PTY LTD	Yes	Yes	Yes	Yes
10	11879	MOUNT ALEXANDER SHIRE COUNCIL	No	Yes	No	NA
11	11908	ELLIOTT HOLDINGS (AUST) PTY LTD	Yes	Yes	Yes	Yes
12	11940	ALTONA NORTH LANDFILL PTY LTD	Yes	No	Yes	Yes
13	11972	WESTERN LAND RECLAMATION PTY LTD	Yes	Yes	Yes	Yes
14	12008	CITY OF BALLARAT	No	No	Yes	No
15	12039	MURRINDINDI SHIRE COUNCIL	No	No	No	No
16	12067	HORSHAM RURAL CITY COUNCIL	Yes	Yes	Yes	Yes
17	12099	GREATER SHEPPARTON CITY COUNCIL	No	No	No	No
18	12129	BASS COAST SHIRE COUNCIL	No	No	No	Yes
19	12160	LANDFILL OPERATIONS PTY LTD	No	No	No	Yes
20	12192	CORANGAMITE SHIRE COUNCIL	No	No	No	No
21	12247	STRATHBOGIE SHIRE COUNCIL	Yes	No	No	No
22	12275	MANSFIELD SHIRE COUNCIL	No results			
23	12309	HANSON LANDFILL SERVICES PTY LTD	No	No	No	No
24	12339	A.J. BAXTER PROPRIETARY LIMITED	No	No	No	No
25	12380	LYNDCADLE PROPRIETARY LIMITED	Yes	Yes	Yes	Yes
26	12409	CALLEJA PROPERTIES PTY LTD	No results			
27	12450	HUME CITY COUNCIL	Yes	Yes	Yes	Yes
28	12483	WYNDHAM CITY COUNCIL	No	No	No	No
29	12512	A.J. BAXTER PROPRIETARY LIMITED	No	No	No	No
30	12554	CLEANAWAY SOLID WASTE PTY LTD	No results			
31	12560	BENALLA RURAL CITY COUNCIL	No	No	Yes	Yes
32	13111	ALPINE SHIRE COUNCIL	Yes	Yes	Yes	Yes
33	13157	HUME CITY COUNCIL	No results			
34	15500	MOIRA SHIRE COUNCIL	Yes	No	No	No
35	18883	CLEANAWAY PTY LTD	No	No	No	No
36	19732	YARRA RANGES SHIRE COUNCIL	No results			
37	19951	MILDURA RURAL CITY COUNCIL	Yes	No	No	No
38	20025	WANGARATTA RURAL CITY COUNCIL	No	No	No	No
39	20474	MITCHELL SHIRE COUNCIL	No results			
40	20720	SOUTHERN GRAMPIANS SHIRE COUNCIL	Yes	Yes	Yes	Yes
41	21125	NILLUMBIK SHIRE COUNCIL	No results			
42	21470	SURF COAST SHIRE	No	No	No	Yes
43	22492	GLENELG SHIRE COUNCIL	No	Yes	No	No
44	24430	EAST GIPPSLAND SHIRE COUNCIL	No results			
45	24532	LATROBE CITY COUNCIL	No results			
46	24873	SOUTH GIPPSLAND SHIRE COUNCIL	No	No	No	No
47	25565	LATROBE CITY COUNCIL	No	No	No	No
48	26457	LATROBE CITY COUNCIL	No results			
49	45248	GROSVENOR LODGE PTY. LTD.	Yes	No	No	No
50	45279	HI-QUALITY QUARRY PRODUCTS PTY LTD	No	No	No	No
51	45288	MADDINGLEY BROWN COAL PTY LTD	No results			

No	Licence No	Licence Name	2013	2014	2015	2016
52	46490	GREATER BENDIGO CITY COUNCIL	No	No	No	No
53	69939	SUEZ RECYCLING & RECOVERY PTY LTD	No results			
54	70000	CENTRAL GIPPSLAND REGION WATER	No results			
55	70081	GREATER GEELONG CITY COUNCIL	No results			
56	70151	GANNAWARRA SHIRE COUNCIL	No results			
57	70183	STATEWIDE RECYCLING SERVICES	No results			
58	70367	MORNINGTON PENINSULA SHIRE COUNCIL	No results			
59	70422	MORNINGTON PENINSULA SHIRE COUNCIL	No results			
60	70542	SUEZ RECYCLING & RECOVERY PTY LTD	No results			
61	70781	MITCHELL SHIRE COUNCIL	No results			
62	70988	MITCHELL SHIRE COUNCIL	No results			
63	72476	GREATER GEELONG CITY COUNCIL	No results			
64	72505	SWAN HILL RURAL CITY COUNCIL	No results			
65	72611	WELLINGTON SHIRE COUNCIL	No results			
66	72667	EAST GIPPSLAND SHIRE COUNCIL	No results			
67	72786	WELLINGTON SHIRE COUNCIL	No results			
68	72826	EAST GIPPSLAND SHIRE COUNCIL	No results			
69	80195	BARRO GROUP PTY LIMITED	NA	Yes	Yes	Yes

APPENDIX H: QLD LANDFILL LICENCES LFG REQUIREMENTS

Summary of the QLD landfill gas requirements as stipulated in the landfill licences.

ERA 60	Landfill Gas requirements
Waste disposal 1: Operating a facility for disposing of, in a year, the following quantity of waste mentioned in subsection (1)(a)	
a) less than 50,000t	No requirement
b) 50,000t to 100,000t	(P9-25) Where a landfill gas monitoring program identifies migration of landfill gas in concentrations greater than 25% of the lower explosive limit for methane at or beyond the boundary of any area of the licensed place used for waste disposal, a landfill gas extraction, a collection and disposal system must be installed into the waste disposal facility so as to prevent or minimise: (a) landfill gas migration through any perimeter embankment; and (b) any uncontrolled emission of landfill gas to the atmosphere. (P9-26) Landfill gas collected by the landfill gas collection system referred to in condition number (P9-25) may only be disposed of: (a) by passive venting to the atmosphere through gas diffusers; or (b) flared prior to release to the atmosphere; or (c) reused.
c) more than 100,000t but not more than 200,000t	(A2.1) A landfill gas management plan must be developed and implemented. The plan must outline actions and timeframes to achieve the following: 1. minimise emissions of landfill gas to the atmosphere; and 2. monitor and minimise the sub-surface migration of the landfill gas to adjacent areas; and 3. maximise the beneficial re-use of landfill gas; and 4. minimise the risk of people being exposed to landfill gas and it reaching concentrations where there is a risk of combustion; and 5. monitoring landfill gas to identify potential volumes, flow rates and composition and concentrations of constituent gases.
d) more than 200,000t	No requirement
Waste disposal 2: Operating a facility for disposing of, in a year, the following quantity of waste mentioned in subsection (1)(b)	
a) 50t to 2,000t	No requirement
b) more than 2,000t but not more than 5,000t	No requirement
c) more than 5,000t but not more than 10,000t	No requirement
d) more than 10,000t but not more than 20,000t	Management of Landfill Gas: Methane Gas Standards (B10) The release of landfill gas from any facility must be such that the concentration of landfill gas must not exceed: (i) 25 percent of the lower explosive limit for methane when measured in facility structures (but excluding facility structures used for landfill gas control and (ii) landfill gas recovery system components); and (iii) the lower explosive limit for methane at the landfill facility boundary.
e) more than 20,000t but not more than 50,000t	Waste (WA25) The holder of this environmental authority must adopt such practices and procedures as necessary to ensure that the concentration of landfill gas (methane standards) generated by Yeppoon landfill does not exceed: a) 25 percent of the lower exposure limit for methane in facility structures excluding gas control or recovery system components; and b) The lower explosive limit for methane at the landfill facility boundary.

ERA 60	Landfill Gas requirements
	Landfill Gas Management (B3) The holder of this environmental authority must adopt such practices and procedures as necessary to ensure that: (a) the concentration of landfill gas (methane standards) generated by the landfill unit does not exceed 25 percent of the lower explosive limit for methane in useable closed spaces located on the facility excluding any gas control or recovery system components; and (b) the concentration of landfill gas components, other than methane, generated by the landfill does not exceed concentrations which may pose a health risk to persons within useable closed spaces located on the facility excluding gas control or recovery system components. **Refer to Note 1**.
f) more than 50,000t but not more than 100,000t	Some licences have: No requirement
	One licence contained: A landfill gas management plan must be developed and implemented. The plan must outline actions and timeframes to achieve the following: 1. minimise emissions of landfill gas to the atmosphere; and 2. monitor and minimise the sub-surface migration of the landfill gas to adjacent areas; and 3. maximise the beneficial re-use of landfill gas; and 4. minimise the risk of people being exposed to landfill gas and it reaching concentrations where there is a risk of combustion; and 5. monitoring landfill gas to identify potential volumes, flow rates and composition and concentrations of constituent gases.
g) more than 100,000t but not more than 200,000t	The release of landfill gas must not cause environmental harm. Landfill gas is not considered to cause environmental harm if: 1. a landfill gas collection system is installed and maintained when the landfill unit is sufficiently elevated to allow adequate drainage of gas lines, and 2. landfill gas monitoring shows that the release of methane does not exceed the following limits: (a) 500 parts per million at a height of 50mm above the final and intermediate cover surface including the batter slopes of the landfill unit (b) 25 percent of the lower explosive limit when measured in facility structures (but excluding facility structures used for landfill gas control and landfill gas recovery system components), and (c) the lower explosive limit at or beyond the landfill facility boundary, and (d) no adverse effects of are caused by subsurface gas to vegetation within Lagoon Creek, Tea Tree Lagoon and the 200 metre riparian buffer zone from the top bank of these waters. A3-9 A collection system for landfill gas must be installed and maintained to efficiently minimise: 1. any likelihood of any subsurface migration of landfill gas from the landfill unit, and 2. any uncontrolled emission of landfill gas. A3-10 Landfill gas collected by the gas collection system must be incinerated prior to release to the atmosphere or provided or used as a fuel source or collected and stored in a proper and efficient manner for later use.

ERA 60	Landfill Gas requirements
	A3-11 The landfill gas collection system must be installed and maintained when each landfill unit is either sufficiently elevated for collection or when an area has been completed.
h) more than 200,000t	Management of Landfill Gas (B3) A collection system for landfill gas must be installed and maintained to efficiently minimise: i. any likelihood of any subsurface migration of landfill gas from the landfill unit; and ii. any uncontrolled emission of landfill gas. (B4) An interim perimeter active landfill gas collection system for all cells must be installed prior to installation of the final gas collection system. This system is to be installed forthwith after the landfill cell is sufficiently elevated to allow adequate drainage of gas lines. (B5) Landfill gas collected by the gas collection system must be incinerated prior to release to the atmosphere or provided as an alternative fuel source or collected and stored in a proper and efficient manner for later use. (B11) There must be no visible emissions from the landfill gas flare. (B12) The release of landfill gas from the landfill must not exceed: i. 25 percent of the lower explosive limit for methane when measured in landfill facility structures (but excluding landfill facility structures used for landfill gas control and landfill gas recovery system components); and ii. the lower explosive limit for methane at the landfill facility boundary.

Note 1:

The licence includes requirements in consideration of the total tonnes disposed, in this licence, 500,000 tonnes is the threshold.

(B4) Where it is estimated that by the cessation of waste disposal activities 500,000 tonnes or more of waste will be disposed of at the licensed place, the holder of this environmental authority must:

(1)submit to the administering authority for review and comment, a proposal to *implement a landfill gas monitoring program* which is to include details of but not be limited to the following information:

- (a) the depth and location of the proposed landfill gas monitoring piezometers;
- (b) piezometer design and construction details;
- (c) frequency of monitoring;
- (d) determinants to be monitored;
- (e) the time scale proposed for the construction of monitoring wells and the implementation of a monitoring program; and
- (f) the parameters and detection limits of monitoring equipment.

(2) install landfill gas monitoring piezometers and implement a landfill gas monitoring program; and

(3)*install an effective gas collection and control system* into any tipping area where the landfill gas monitoring program detects landfill gas in concentrations greater than:

- (a) 25% of the lower explosive limit for methane in facility structures other than the gas control units or parts thereof; or
- (b) the lower explosive limit for methane at the landfill boundary.

APPENDIX I: COMPARATIVE THEORETICAL ANALYSIS OF THE REGULATORY PROPORTION IN EACH STATE

In the absence of information from project offsets reports (not available to the authors), we carried out a theoretical analysis of the regulatory baseline calculations for three (3) scenarios. The scenarios shown in Table 28, were considered. The scenarios consider three different site sizes (areas) for each state. We therefore calculated the allowable flux and the actual flux (using the NGER calculator). This calculation intends to demonstrate how the regulatory proportion is estimated.

Assumptions:

- The site opened in 2000
- Accepted 100kt/yr comprising 40% MSW (class 1), 40% C&I, 20% C&D
- GWP CH_4: 25 [source: NGER (Measurement) Determination]
- OF: 10% [source: NGER (Measurement) Determination]

Table 28: Illustrative example scenarios considered

Variable/Scenario	**A**	**B**	**C**	**Methane Concentration limit (CH_4 ppm)**	**Permitted methane flux rate ($tCH_4/m^2/hr$)**
Site area (ha)	40 ha	20 ha	10 ha		
Proportion of site under final cover	100%	100%	100%		
Allowable 2017 flux (tCO_2-e) – [$M_{Reg,FI}$]					
NSW, QLD, WA, TAS	243,333	121,667	60,833	500	2.5×10^{-6}
ACT, VIC	29,200	14,600	7,300	100	0.3×10^{-6}
NT, SA	no limit	no limit	no limit	n/a	n/a

The allowable 2017 flux was calculated using equation 22 of the Methodology, which is:

$$M_{Reg,FI} = \frac{8760 \times GWP_{CH_4}}{(1 - OF)} \times \sum_x (S_x \times C_x)$$

As an example, for a landfill site in the ACT under scenario A, the following formula would apply.

$$M_{Reg,FI} = \frac{8760 \times 25}{(1 - 0.1)} \times \sum (400{,}000 \times 0.3 \times 10^{-6})$$

The estimated actual 2017 emissions (t CO_2-e) were obtained from the NGER calculator and are presented in Table 29. The estimates assume fluxes per unit area are identical.

Table 29: Estimated annual emissions (i.e. flux through final cover) (t CO_2-e)

State	Estimated annual emissions (t CO_2-e)
QLD, NT (fast degradation rates)	91,887
NSW (intermediate degradation rates)	85,831
ACT, SA, TAS, VIC, WA (slow degradation rates)	60,721

Table 29 provides a summary of the outcome of scenario testing which have been estimated based on the regulatory proportions for theoretical landfills by jurisdiction. To obtain those results, the following formula was used:

$$Regulatory\ Proportion = 1 - \frac{Allowable\ 2017\ flux}{Flux\ through\ final\ cover}$$

As an example, for a landfill site in the ACT under scenario A, the following formula would apply.

$$Regulatory\ Proportion = 1 - \frac{29{,}200\ tCO_2e}{60{,}721\ tCO_2e} = 1 - 0.48 = 0.52 = 52\%$$

Table 30: Regulatory proportion

State	A	B	C
ACT	52%	76%	88%
NSW	0%	0%	29%
NT	0%	0%	0%
QLD	0%	0%	34%
SA	0%	0%	0%
TAS	0%	0%	0%
VIC	52%	76%	88%
WA	0%	0%	0%

The three scenarios for each State is presented in

Figure 26. The default baseline is also highlighted.

Figure 26: Outcome of scenario testing (graphical) – estimated proportions by State

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Analysis of Waste Sector Projects and Methods

DELIVERABLE 2:
Performance of the landfill gas method against the offsets integrity standards

FINAL

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ABBREVIATIONS AND ACRONYMS

Abbreviation/ Acronym	Description
ACCU	Australian Carbon Credit Unit
BPEM	Best Practice Environmental Management
CDM	Clean Development Mechanism
CH_4	Chemical formula for Methane
CFI Act	The *Carbon Credits (Carbon Farming Initiative) Act 2011*
CFI Methodology Determination	See Methodology
DE	(Methane) Destruction Efficiency
DOC	Degradable Organic Carbon
DoEE	Department of the Environment and Energy
Eff	Electrical efficiency factor
EPA	Environmental Protection Agency
ERF	Emissions Reduction Fund
EU	European Union
GGAS	NSW Greenhouse Gas Reduction Scheme
GHD	GHD Australia Pty Ltd
GHG	Greenhouse Gas
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
kW	Kilowatt
kWh	Kilowatt hour
Landfill gas method	See Methodology
LCA	Life Cycle Analysis
LFG	Landfill gas
LGC	Large-scale generation certificates
Method	See Methodology
Methodology	Either: *Carbon Credits (Carbon Farming Initiative—Landfill Gas) Methodology Determination 2012*, or *Carbon Credits (Carbon Farming Initiative—Landfill Gas) Methodology Determination 2015* If not specified, assume the current 2015 version of the Methodology is meant
MWe	Megawatt electric
MWh	Megawatt hour
NCT	Non-Carbon Tax
NGER Act	The *National Greenhouse and Energy Reporting Act 2007*

Abbreviation/ Acronym	Description
NGER (Measurement) Determination	The National Greenhouse and Energy Reporting (Measurement) Determination 2008
POEO	Protection of the Environment Operations
ppm	parts per million
Regulation	The Carbon Credits (Carbon Farming Initiative) Regulations 2011
Resource Intelligence	Resource Intelligence Pty Ltd
RET	Renewable Energy Target
SMEC	SMEC Australia Pty Ltd
UNFCCC	United Nations Framework Convention on Climate Change
WMAA	Waste Management Association of Australia

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Due to the inherent limitations in any internal control structure, it is possible that fraud, error, or non-compliance with laws and regulations may occur and not be detected. Furthermore, this assessment was not designed to detect all cases in which projects under the *Carbon Credits (Carbon Farming Initiative—Landfill Gas) Methodology Determination 2012* and *Carbon Credits (Carbon Farming Initiative—Landfill Gas) Methodology Determination 2015* may have been inappropriately issued with units. Some statements made in this report are opinions made on a subjective basis, or based on project experience which cannot, for reasons of confidentiality, be specifically detailed.

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EXECUTIVE SUMMARY

This report examines the performance of *the Carbon Credits (Carbon Farming Initiative—Landfill Gas) Methodology Determination 2012* and *2015* (the more widely used version) (referred to as the "Methodology") against the offsets integrity standards.

Whether the Methodology is supported by clear and convincing evidence

The Methodology's approach to calculating greenhouse gas (GHG) emissions abatement seems appropriate. The Methodology focuses on direct measurement of key parameters: the quantity of methane and the baseline portion to be offset.

The Methodology clearly sets out the equations and how these should be applied to quantify the methane sent to destruction devices. The equations utilised vary depending on the project type, therefore the equations used are tailored in different projects. The Methodology uses direct measurement by scientifically robust devices consistent with legislative or relevant standards, calculations and assumptions. Default values are, where practical, aligned with the NGER (Measurement) Determination and consistent with other international methods such as the Clean Development Mechanism (CDM).

There are some differences between the 2012 and 2015 versions of the Methodology, although they will yield approximately the same output if the same options are selected. However, they differ in the circumstances in which different options may be selected, and have slightly different system boundaries and parameter requirements. In general, the default values in both versions are conservative and do not have a material influence on the calculated abatement. The areas of least rigour are:

a) The ability to use a default methane concentration of 50% (at any time in the 2012 version, and until measurement is in use in the 2015 version) even when the actual methane percentage is lower.
b) The default value of electrical efficiency of 36%. It can vary between different engine types, how well they are operated and maintained, and the load factor at which they are operated.
c) Instruments are required to be calibrated to manufacturer specifications, but manufacturers generally do not specify calibration frequency or may not consider landfill gas conditions.
d) Both versions of the Methodology are silent on how moisture in landfill gas is allowed for. There is a potential to overstate methane flow by approximately 2% to 7%.
e) The 2015 Methodology does not clearly specify reporting requirements.

Additionality and baseline assumptions

The additionality tests exclude non-additional abatement where practicable. Most of the baseline and default factors are deemed appropriate. The most important factor for the landfill gas Methodology in excluding non-additional abatement is the use of an appropriate baseline. The Methodology adopts a default 30% qualitative baseline.

Regulations of landfills follow a tiered approach: state legislation and regulation, landfill guidelines, and site-specific licences. The focus, regulation and enforceability of requirements vary across Australia. There is no explicit indication in the regulations of how the size of a landfill and its proximity to population centres affects gas capture requirements.

Legislative or regulatory requirements and guidelines specifically requiring landfill gas capture at landfills relate primarily to risk management activities (e.g. odour, toxicity and explosion risk), rather than GHG emissions abatement activities. Although the requirements usually do result in GHG emissions mitigation, it should be noted that these requirements do not specify how much landfill gas must be managed (e.g. captured and combusted). Landfill gas combustion seems to be the most effective and economical means to address the requirements. Alternatives such as better capping materials are not covered by the Methodology. Key factors affecting the proportion of maximum possible gas collection are depth, width, type of waste, leachate issues, temperature and rainfall, type of cap, type of lining and how well the landfill is managed in general.

Tighter (i.e. lower) landfill gas action levels in Victoria and the ACT create a higher regulatory proportion, modelled as 52%-88% depending on the landfill size. As such, in these cases, the regulatory proportion is higher than the default baseline of 30%. Consequently, the regulatory proportion needs to be selected as the site's baseline. It is noted that the default baseline of 30% of landfill gas collected and combusted (not gas generated) was negotiated between the government and the industry in 2011.

Upon entering an extension period, the qualitative baseline assumption, the use of a default 50% methane concentration, and the Non-Carbon Tax reduction could be reviewed.

Uptake, financial considerations, barriers

Historically, most state and territory government support programs in the waste sector have addressed recycling. Landfill gas capture has been encouraged by state, territory and local governments mainly in response to odour and risk management. Additional to the Emissions Reduction Fund (ERF) program, other financial incentives associated with landfill gas capture and combustion are the sale of electricity generated and the creation and sale of Large Scale Generation Certificates (LGCs).

The establishment of most landfill gas collection systems correlates with the introduction of financial incentives from the creation of GHG emissions abatement and/or the generation of renewable electricity. These incentives appear to drive and maintain investment in landfill gas collection. Without them, investment is likely to commence later in the lifecycle of cells and be lower, leading to collection rates declining in existing projects. This conclusion is more certain in relation to landfill gas flaring but also applies to power generation projects.

For a landfill gas capture, flare and power generation system, over the timeframe considered (seven years), the capital costs represent approximately 50% of the costs, ongoing costs (e.g. operation and maintenance of the gas capture and conditioning) represent approximately 30% of the costs, and power generation overhauls represent approximately 20% of the total costs. For a landfill gas capture and flaring system, these costs would be approximately 40% for the capital costs and 60% for the ongoing costs.

The ACCUs contribute to revenue in both power generation and flare projects. Without the ACCUs, these projects may not be financially viable over the seven years' crediting period. This may be the case even after the revenue streams from the sale of electricity and LGCs for applicable projects.

All landfill gas projects accredited are currently considered additional. An extension of the crediting period will enable GHG emissions from these projects to continue to be maximally abated. The continuous cell development process in landfills means that ongoing investment is required if landfill gas capture and management is to be maintained. If financial incentives such as from the creation of ACCUs and electricity generation (as applicable) are not available, gas collection and management may decline.

There are barriers to new projects that would provide genuine and additional abatement, including:

- the qualitative baseline greater than the default 30%, particularly for potential projects in Victoria where a lower maximum parts-per-million (ppm) of methane concentration above the surface of the landfill is specified; and
- the Non-Carbon Tax waste percentage calculations, particularly for small landfills which do not need to carry out this calculation for NGER reporting.

Conclusions Summary

Table 1 provides a summary of the conclusions made.

Table 1: Conclusions Summary

No.	Conclusions
Conclusion 1	The additionality tests exclude non-additional abatement where practicable. The most important factor for the landfill gas Methodology in excluding non-additional abatement is the use of an appropriate baseline.
Conclusion 2	The default methane percentage of 50% can be used for extended periods when the actual methane percentage may be materially lower. For example, if a site claims 50% methane concentration but the actual is 40%, then the claimed units would be 25% higher than actual landfill gas destruction.
Conclusion 3	Tighter (i.e. lower) landfill gas action levels in Victoria (and the ACT) create a higher regulatory proportion, modelled as 52%-88% depending on the landfill size. As such, in these cases, the regulatory proportion is higher than the default baseline of 30% (for non-transitioning projects). The Methodology says therefore, the regulatory proportion needs to be selected as the site's baseline.
Conclusion 4	The current Methodology approach to calculating abatement seems appropriate. It is noted that the default baseline of 30% (for non-transitioning projects) of landfill gas collected and combusted (not gas generated) was negotiated between the government and the industry in 2011. There has not been a subsequent operational data review and re-calculation will require a more thorough investigation. It is expected that amongst others, the geographical location (a factor in the organic decomposition rates, and hence the landfill gas generation rates) would be considered.
Conclusion 5	The establishment of most landfill gas collection systems correlates with the introduction of financial incentives from the creation of GHG emissions abatement and/or the generation of electricity. Gas collection in 2015 was 2.5 times (8,070 ktCO2-e in 2015 versus 3,210 ktCO2-e in 2002) than before incentives (beyond the value of electricity) were introduced in 2003. These incentives appear to drive and maintain investment in landfill gas collection. Without them, investment is likely to commence later in the lifecycle of cells and be lower, leading to collection rates declining in existing projects. This conclusion is more certain in relation to landfill gas flaring but also applies to energy generation projects.
Conclusion 6	Legislative or regulatory requirements specifically requiring landfill gas capture at landfills relate primarily to risk management activities (e.g. odour, toxicity and explosion risk), rather than GHG emissions abatement activities. Management tools other than collection/flaring, such as better capping materials, could achieve legislative compliance but at a lesser rate of GHG emissions abatement.

No.	Conclusions
Conclusion 7	Landfill gas capture is mentioned in State and Territory guidelines on appropriate landfill management. Nevertheless, these guidelines focus on potential environmental and health and safety risks such as; methane concentrations at the boundary of the site, odour and potential impact on receptors and potential gas migration pathways. Landfill gas combustion seems to be the most effective (and given the financial incentives), the most economical means to address these requirements. Nevertheless, landfill sites might implement other activities (refer to section 2.4.1.1) that will result in compliance with the guidelines without the abatement of GHG emissions.
Conclusion 8	Landfill licences vary across States and within States (e.g. depending on the landfill size) and are applicable to individual sites. Some landfill licences do require landfill gas capture and management. Despite the requirement being intended to mitigate potential risks, these requirements result in GHG emissions mitigation. It is noted that because these requirements do not specify the extent of (i.e. how much gas) landfill gas that must be managed (e.g. captured and combusted), these requirements account for the 30% qualitative baseline in the Methodology.
Conclusion 9	The existing baseline arrangements in the Methodology may represent a barrier, particularly for potential projects in Victoria where a lower maximum parts-per-million (ppm) of methane concentration above the surface of the landfill, can result in a baseline greater than the default 30%.
Conclusion 10	The non-carbon tax emissions calculation requirement may present a barrier, particularly for small landfills which do not need to carry out this calculation for NGER reporting.
Conclusion 11	The baseline determination is the major reflection of additionality for a landfill gas project. The current default baseline of 30% was evaluated in 2011. Data from projects in operation since then could be used to develop new baselines, particularly to determine additionality levels upon entering an extension period.
Conclusion 12	The continuous cell development process in landfills, means that ongoing investment is required if gas capture and management is to be maintained. If financial incentives such as from the creation of ACCUs and electricity generation (as applicable) are not available, gas collection and management may decline.
Conclusion 13	The baseline abatement can be quantified using the calculation approaches set out in equations 12 to 19 of the 2015 Methodology. To assess this the equations in the Methodology (summarised in Figure 8) have been reviewed and allow quantification. The Methodology, explanatory statement, and guidance are sufficient for this to be calculated and verified.
Conclusion 14	By conducting a detailed review of all of the equations and parameters in the 2015 Methodology (summarised in Table 11), it is clear that the abatement delivered by eligible projects can be quantified using the calculation approaches set out in the Methodology. Net abatement in the Methodology is fully verifiable if the equations have been worked out correctly and the supporting data for each parameter is available.

No.	Conclusions
Conclusion 15	Abatement delivered by eligible projects can be quantified using the calculation approaches set out in the Methodology. This is dependent on the project proponent collecting and appropriately applying the required data. This conclusion is supported by reviewing all the equations and parameters required in the Methodology. As such, the following is confirmed: ▪ The calculation approaches are straightforward and mathematically robust. ▪ The net abatement calculations are an accurate representation of reality. ▪ The Methodology focuses on direct measurement of the key parameters that determine the ACCUs (i.e. the quantity of methane sent to (and destroyed by) the combustion device). ▪ The 2012 and 2015 Methodologies will yield approximately the same output if the same options (e.g. selecting the default, not measurement data) are selected. ▪ However, the two Methodologies differ in the circumstances in which different options may be selected and have slightly different system boundaries and parameter requirements. ▪ Nonetheless if the project proponent follows the equations outlined in the Methodology the net abatement can be accurately calculated. ▪ The calculated abatement is fully verifiable if the project proponent has followed the requirements for monitoring, measurement and data collection (as assessed in section 3.2)
Conclusion 16	Measuring requirements are defined as being consistent with NGER (Measurement) Determination specifications and in turn with relevant standards such as the National Measurement Act 1960. This is considered to be scientifically and technically robust as Australian Standards must be adhered to. The Methodology clearly specifies these requirements and makes references to external sources in an accurate and appropriate way.
Conclusion 17	As the 2015 Methodology does not clearly specify the data collection requirements it can be concluded that they are not adequately specified.

No.	Conclusions
Conclusion 18	There are some differences and similarities between the 2012 and 2015 Methodologies. The areas of least rigour are: a) The ability to use a default concentration of 50% (if measurement not already in use in the 2015 Methodology, and at any time in the 2012 Methodology). b) Electrical efficiency can vary between different engine types, how well they are operated and maintained, and the load factor at which they are operated. All engines would be expected to have a technical specification. The default value of 36% is likely to be conservative and therefore appropriate. c) Instruments must be calibrated to manufacturer specifications. Nevertheless, manufacturers generally do not specify calibration frequency for flow, temperature and pressure instruments. Furthermore, specifications may not be fully valid for landfill gas conditions (landfill gas can be moist, contain dirt particles and microbiological content).
Conclusion 19	The calculations set out in both the 2012 and 2015 Methodology allow the abatement delivered by the project to be quantified through the use of scientific measurements. Equations used vary depending on the project type so the use of calculations is tailored to different projects. The volume of landfill gas sent to a destruction device is measured by scientifically robust devices. The process of then converting landfill gas to volume of methane and amount of methane destroyed is also robust as this uses common methods for destruction efficiency. This excepts the use of some of the default values. In general, the default values are conservative and do not have a material influence on calculated abatement.
Conclusion 20	The Methodologies clearly set out the equations and how these should be applied to quantify the volume of landfill gas sent to destruction devices.
Conclusion 21	By reviewing the Methodologies, it can be concluded that the measurement and monitoring requirements refer to external references where appropriate and required.
Conclusion 22	The Methodology has taken reasonable steps to minimise uncertainty in measurement and data collection. Most measurement requirements are relatively straightforward and reduce uncertainty (e.g., gas flow measurements need to be within strict uncertainty limits). With the measurement of gas flow and methane concentration there is some inherent uncertainty as specified by manufacturer measurement devices.
Conclusion 23	The 2015 Methodology reporting requirements are not clearly specified, for example it does not state that the abatement calculations, parameters, and data sources need to be included in the offsets report. It is therefore recommended that these are more clearly specified so that project managers know what level of detail is required, and so there is a more standardised and common approach to reporting. Of the projects reviewed there is an apparent variability in reporting, this supports the conclusion that the reporting requirements are not clearly specified.

No.	Conclusions
Conclusion 24	There is a risk with the 2015 Methodology that, as the reporting requirements are limited, not all the information would be required to be kept under the record-keeping requirements (sections 192 and 193 of the CFI Act require records to be kept if this is used in preparing the offsets report). If the offsets report does not specify much detail, then it is possible that the project proponent may not retain all the required information necessary to demonstrate compliance with the Methodology. This is a potential issue when it comes to the verification of methodology compliance.
Conclusion 25	Record keeping requirements in the 2015 Methodology do not include all information required to demonstrate compliance with the Methodology in full. As the auditor is verifying compliance with the whole Methodology the record keeping requirements could be specified in additional detail to assist with the verification process.
Conclusion 26	Record-keeping requirements, as defined in the CFI Act, require project proponents to retain records if they are used in the preparation of the offsets report. There are some gaps in the specific detail to be included in offsets reports that could lead to required information not being recorded. Furthermore, if the reporting and record-keeping requirements do not cover all aspects of the Methodology, then it could be difficult for an auditor to verify that all requirements in the Methodology have been met.
Conclusion 27	In the 2015 Methodology, the abatement calculations should be verifiable (i.e. the project must provide the required data to support each parameter and assumption used in the equations). However, the record keeping requirements (when compared to the 2012 Methodology) are very limited in detail and do not explicitly specify the records that must be kept. In contrast, section 4.4 of the 2012 Methodology is very specific in the record keeping requirements. As such, the 2012 Methodology is more straightforward to verify than the 2015 Methodology.
Conclusion 28	There are differences between the 2012 and 2015 Methodologies regarding the record keeping requirements. The 2012 Methodology has relatively detailed and specific record keeping requirements which potentially reduce the flexibility in the type of evidence available to proponents. However, this is likely to make the verification process more straightforward. Contrastingly, the 2015 Methodology has limited record-keeping requirements, which increases the flexibility in evidence requirements, but can potentially create more issues in the verification process.
Conclusion 29	There are not many aspects of the CFI Methodology Determination where the type of evidence has much flexibility, i.e., equipment and instrument data obtained from the monitored parameters is likely to only be derived from one source. Hence, whilst there could be some flexibility, the methods are prescriptive in the data that is required for the abatement calculations.
Conclusion 30	There are no apparent projections used under the landfill gas Methodology as it is reliant on direct measurement and calculations. When compared to other CFI/ERF methods (other than previously discussed estimations/assumptions) the landfill gas Methodology is considered to use appropriate and conservative values. Furthermore, wherever practical, these are aligned with NGER (Measurement) Determination methods which are comparable to other international methods such as the CDM.

No.	Conclusions
Conclusion 31	In terms of whether the 30 per cent default regulatory proportion defined in section 28 of the Methodology is supported by clear and convincing evidence, the authors of this report have not been able to assess all the source of information that underpin that statistic. Nevertheless, the input parameters (which are available) appear to be appropriate.
Conclusion 32	The baseline abatement can be quantified using the calculation approaches set out in equations 12 to 19 of the Methodology. These equations are straightforward and their logic is clear. The ongoing 'grandfathered' baselines for pre-existing CFI projects may or may not be conservative, but the ability to use them is a clear legislative right.
Conclusion 33	The data obtained shows a trend that bigger landfills have higher emissions which would be expected. However bigger landfills also tend to capture more of the landfill gas so the emissions per tonne of waste received is in general lower for larger landfills.
Conclusion 34	Data on landfill tonnes per annum can be very difficult to obtain in the public domain. For some landfills, it was possible to obtain this data from literature searches, however whilst all sites were searched for it is apparent that this information is not readily available. It is therefore recommended that the state and federal Governments try to collate this information together so it is more available.
Conclusion 35	Scope 1 GHG emissions data for landfills provided by the CER highlights some issues in this data collection and quality. For instance, there are a significant number of facilities that have only reported for one year, not all years, or have stopped reporting altogether. There could be valid reasons for this such as being below a reporting threshold, change of name, data missing, etc. however it would be expected that landfills should have relatively consistent emissions profiles year on year so some further investigation into the scope 1 emissions reported under NGER or State Governments should be undertaken.
Conclusion 36	For ERF projects the waste received at a landfill (split by waste type / composition) is required for calculated abatement. It would be useful if the CER or DoEE collated this information so further analysis can be performed of different landfill characteristics.
Conclusion 37	Key factors affecting the proportion of maximum possible gas collection are depth, width, type of waste, leachate issues, how hot the climate is, how wet the climate is, type of cap, type of lining, and how well the landfill is managed in general. The NGER Measurement Determination assumes that a maximum 75% of gas generated can be collected; actual practice anecdotally and from literature varies from zero (no collection) to under 50% for poorly managed sites to over 95% at sites with the most effective collection management. Note that the percentage of gas collection is not a factor considered in the 2012 or 2015 Methodologies; crediting is on the basis of tons of methane oxidised above the baseline proportion.

No.	Conclusions
Conclusion 38	For a landfill gas capture, flare and power generation system, over the life of asset considered (seven years), the capital costs represent approximately 50% of the costs and the ongoing costs (e.g. operation and maintenance) represent approximately 30% of the total costs and the power generation overhaul represent approximately 20% of the total costs. For a landfill gas capture and flaring system, these costs would be approximately 40% for the capital costs and 60% for the ongoing costs. This is mainly due to the operation and maintenance requirements of the landfill gas capturing system.
Conclusion 39	ACCUs are a strong incentive for power generating projects. In consideration of the life of asset (seven years), the ACCUs contribute to achieving revenue from both the power generation project and the landfill gas capture and flare project. Nevertheless, without the ACCUs and in consideration of the revenue streams from the sale of electricity for applicable projects, these projects may present a loss over the life of asset.

PERFORMANCE OF THE LANDFILL GAS METHOD AGAINST THE OFFSETS INTEGRITY STANDARDS

This report addresses the following requirements as agreed between SMEC Australia and the Department of the Environment and Energy (DoEE):

- Requirement 2: Assessment of whether carbon abatement supported by the method is unlikely to occur in the ordinary course of events (section 2);
- Requirement 3: Assessment of whether the emissions removal or reduction, as the case may be, are measurable and capable of being verified (section 3);
- Requirement 4: Assessment of whether the method is supported by clear and convincing evidence (section 4);
- Requirement 5: Assessment of whether estimates, projections or assumptions are conservative (section 5); and
- Requirement 6: Provide data and an analysis of landfill gas capture and combustion projects (section 6).

2 Assessment of whether carbon abatement supported by the method is unlikely to occur in the ordinary course of events

2.1 Whether foreseeable activities or circumstances that would be likely to result in non-additional abatement are excluded, where practicable.

Section 27(4A) of the *Carbon Credits (Carbon Farming Initiative) Act 2011* (CFI Act) sets out three tests for additionality:

- The newness requirement (section 2.1.1);
- The government program requirement (section 2.1.2); and
- The regulatory additionality requirement (section 2.1.3).

The three tests, as stated in the CFI Act, exclude non-additional abatement from being credited with Australian Carbon Credit Units (ACCUs). However, the additionality tests are adjusted for some Methodologies. The CFI Act provides for caveats for each of the three tests that allow either Carbon Credits (Carbon Farming Initiative - Landfill Gas) Methodology Determination 2015 (the Methodology) or legislative rules to specify other requirements that can be used in lieu of, or in addition to, the stated additionality tests.

2.1.1 Newness test caveat for landfill gas

There is a caveat for the newness requirement in the landfill gas Methodology. This applies to a small class of recommencing landfill gas projects which have been inactive for over three years. The newness caveat is included to encourage operators to reinvigorate old landfill gas systems that are no longer operational.

It appears unlikely that a landfill would stop operating a landfill gas system for three years solely to subsequently create ACCUs. This is because operators of most reasonable sized landfill gas systems would not be easily able to stop operations for three years due to:

- risk management focus regulatory requirements (section 2.4),
- equipment deterioration and associated costs (sections 2.3.1 and 6.3), and
- potential community concerns over odour.

The newness caveat is therefore considered to exclude non-additional abatement.

2.1.2 Government program requirement caveat

There is no government program requirement caveat for the landfill gas Methodology. All landfill gas projects meet the CFI Act's government program additionality requirement. That is, if a landfill gas system is new and it is not being supported by another Government program, it receives accreditation under the landfill gas Methodology by the fact that it is a landfill gas project.

2.1.3 Regulatory additionality caveat for landfill gas

The material caveat for the landfill gas Methodology is the requirement in lieu of regulatory additionality that *if the project is a landfill gas project it passes the regulatory additionality test*. To manage the regulatory additionality test, *baselines* are applied to exclude non-additional abatement (i.e., a landfill gas project does not receive ACCUs for all the methane it destroys). The baseline reduces the number of ACCUs the project receives based on the amount of gas that would have had to be captured for regulatory purposes had the project not been accredited under the Emissions Reduction Fund (ERF).

<u>*Example*</u>:

If a project has a 30% baseline, and destroys 100 t CO_2-e of landfill gas in a reporting period, the project will receive credit for only 70 t CO_2-e of methane destruction, because the baseline assumes 30 t CO_2-e would have been destroyed anyway because of regulatory requirements.

<u>Conclusion 1</u> The additionality tests exclude non-additional abatement where practicable. The most important factor for the landfill gas Methodology in excluding non-additional abatement is the use of an appropriate baseline.

The application of the baseline forms part of the *regulatory additionality test*. It determines how many ACCUs can be created, based on how much gas would need to be captured to meet regulatory requirements. It is noted that it is not possible to capture all gas emitted from a landfill. Regulatory requirements for gas capture vary greatly between jurisdictions and between sites. Figure 1 provides information on the variety of mechanisms each state and territory use to regulate and guide landfills.

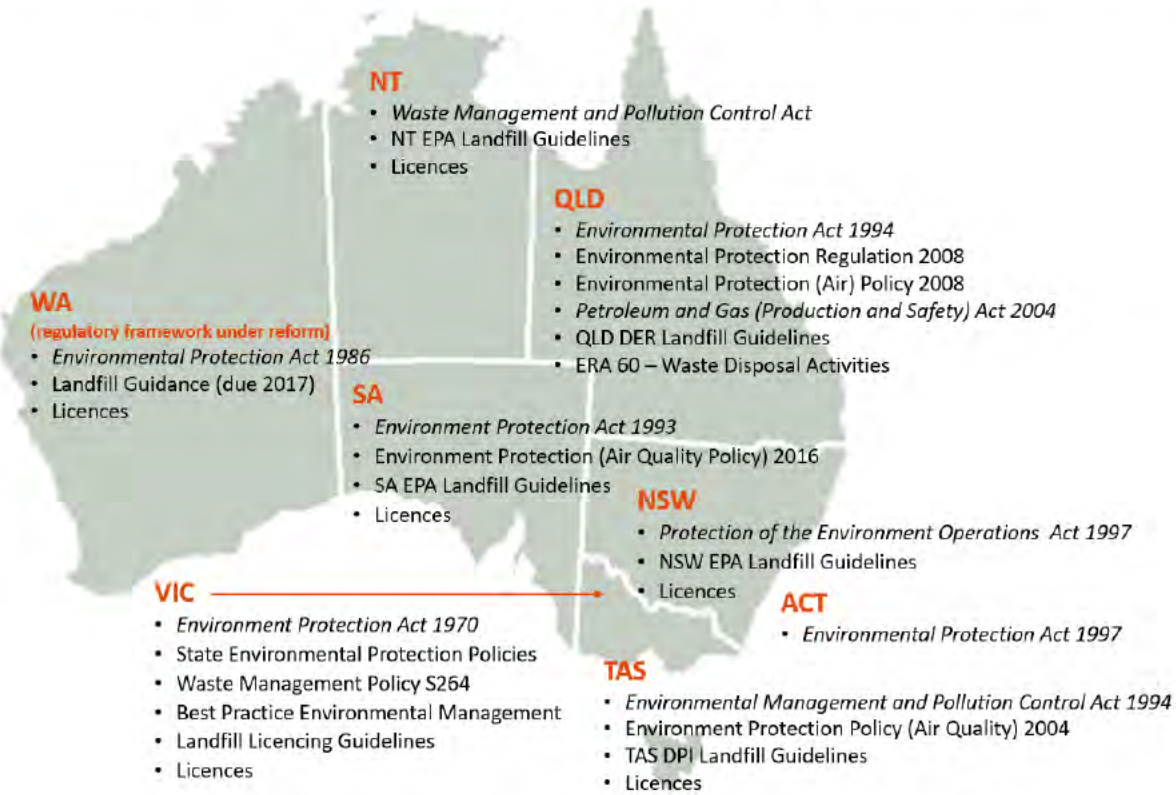

Figure 1: State and Territories waste regulatory framework and requirements

The principal reasons for regulatory requirements to capture gas include the management of risks associated with pollution, occupational health and safety, odour, and importantly for this report, in some cases, greenhouse gas (GHG) emissions minimisation. This is examined in more detail in section 2.4.

2.2 Whether the approach to calculating abatement—including the calculation of baselines and the use of discounts and other adjustments—results in the crediting of abatement that is unlikely to occur in the ordinary course of events.

Summary:

When the baseline and other default factors needed to be determined in 2011 there was less information and data available. Most of the baseline and default factors currently used are deemed appropriate. A review could be undertaken of the 30% default baseline, the use of a default 50% methane concentration, and the Non-Carbon Tax reduction.

The overall approach of calculating abatement by following and applying the 22 sequential equations in the Methodology seems robust and is generally consistent with international landfill gas carbon credit methods. The material default variables and measurements within the landfill gas Methodology are:

- Default Factors (section 2.2.1):
  - Default methane percentage.
  - Destruction efficiency of flares and engines.
  - Global warming potential (GWP) of methane.
  - Energy content of landfill gas.
  - Oxidation factor.
  - Electrical efficiency of engines (for electricity generation).
- Measurement Methods (section 2.2.2):
  - Measurement of methane sent to a combustion device.
  - Measurement of energy content of landfill gas sent to combustion device.
  - Measurement of electricity produced by a landfill gas engine.
- Non-carbon tax waste percentage (section 2.2.3).
- Baseline (section 2.2.4).

2.2.1 Default factors

2.2.1.1 Default methane percentage

The default methane percentage is set at 50%. This represents a reasonable and conservative average estimate, but it is possible to operate a flare with methane concentrations lower than 40%. Low methane concentrations can occur, particularly towards the end of the methane generation cycle from a waste body. Gas composition analysers are widely used in landfill gas collection systems, and may be used in ERF projects, but are not compulsory. Once a project has used measurement it must continue to do so under section 24(3) of the current (2015) Methodology, but if the project commences using the default value it can continue to be used indefinitely. Projects still using the 2012 Methodology can change to and from the default factor as they wish.

There is an unquantified risk of 'gaming', where projects measure concentration only where it is financially advantageous to do so. It was not possible to assess the likelihood of gaming, but detailed assessment of a project's methane percentage and the use of default factors (if available) could provide some insight on the potential methane overestimation.

For example, if the default methane percentage of 50% is used, when gas samples indicate an actual concentration of, say, 40%, then the claimed units would be 25% higher (50% - 40% = 10%, divided by 40%) than actual gas destruction.

A high-level literature review was performed to determine the minimum methane percentage a flare and a power generation engine can operate. The findings are provided below.

2.2.1.2 Minimum methane percentage - flaring

Parker et al 2002[1] indicate that the minimum volume concentration of methane for flaring is 20% (i.e. this concentration enables the landfill gas to form a combustible mixture with ambient air). As such, at 20% methane, only the landfill gas is needed for the flare operation. At landfills with methane concentration of less than 20%, supplemental fuel (e.g. natural gas) is required to operate flares. It is noted that in the industry, based on Australian conditions and depending on the equipment and moisture levels of the gas, the minimum methane percentage required to operate a flare is believed to be underneath 40%. The preference is to operate above 40%.

2.2.1.3 Minimum methane percentage – power generation

Performance of the electricity generation engine operated with landfill gas significantly depends on:

- the methane concentration on the landfill gas; and
- impurities in the landfill gas (i.e. hydrogen sulphide, chlorinated and fluorinated compounds cause corrosion of the engine parts and decrease life of the engine oils).

Literature indicates that the presence of high level of impurities reduce the economic viability of energy recovery[2]. Furthermore, minimum methane concentration required for an engine to work was found to be as low as 35% in the landfill gas[3]. It is noted that this concentration was recorded by an engine manufacturer and does appear to be too low for the industry. Other source[4] reports that the methane concentration, evaluated by field measurements at 3 landfill sites, ranged from 41% up to 98%.

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[1] Parker, T., Dottridge, J. and Kelly, S., (2002) Investigation of the composition and emissions of trace components in landfill gas. Environment Agency, R&D Technical Report P1-438/TR. Accessed 29/08/2017, retrieved from: http://gassim.co.uk/documents/P1-438-TR%20Composition%20of%20Trace%20Components%20in%20LFG.pdf

[2] Sevimoğlu, O. and Tansel, B., (2013) Effect of persistent trace compounds in landfill gas on engine performance during energy recovery: a case study. Waste management, 33(1), pp.74-80.

[3] Ibid. p. 80.

[4] Spokas, K., Bogner, J., Chanton, J.P., Morcet, M., Aran, C., Graff, C., Moreau-Le Golvan, Y. and Hebe, I., (2006) Methane mass balance at three landfill sites: What is the efficiency of capture by gas collection systems?, Waste management, 26(5), pp.516-525 in Di Maria, F., Sordi, A. and Micale, C., (2013) Experimental and life cycle assessment analysis of gas emission from mechanically–biologically pretreated waste in a landfill with energy recovery. Waste Management, 33(11), pp.2557-2567

Conclusion 2 The default methane percentage of 50% can be used for extended periods when the actual methane percentage may be materially lower. For example, if a site claims 50% methane concentration but the actual is 40%, then the claimed units would be 25% higher than actual landfill gas destruction.

2.2.1.4 Oxidation factor

The oxidation factor of 10% is dealt with in detail in section 4.1.5.4.

2.2.1.5 Other default factors

The other five default factors listed above generally follow international guidelines or NGER Act determinations and are considered appropriate. For example, the default methane destruction efficiency for a combustion device[5] of 0.98 is based on the use of an enclosed flare, which is the most usual arrangement for safety and control reasons. The default methane destruction efficiency for an internal combustion engine device of 1.00 appears reasonable for large internal combustion engines such as electricity generators.

2.2.2 Measurement methods

Section 24 of the Methodology provides three options to quantify the methane destroyed. The three measurement options are;

- Option 1 – using landfill gas sent to a combustion device;
- Option 2 – using energy content of landfill gas sent to combustion device; and
- Option 3 – using electricity produced by internal combustion engine.

The three options follow robust techniques that have precedent set in other internationally recognised landfill gas carbon credit methodologies and apply a robust metering solution.

It is noted that Option 1 provides two ways to determine the methane percentage to be considered, which are:

a) As set out in section 5.14C of the NGER (Measurement) Determination (i.e. the default method, which estimates the methane concentration to be 50%); or
b) worked out in accordance with the monitoring requirements (i.e. the measurement method).

The effect of this is discussed in section 2.2.1.1.

2.2.3 Non-Carbon Tax percentage

In the context of the landfill gas Methodology, it is unclear why emissions from waste deposited during the carbon tax years should be excluded. Emissions of landfill gas start a year after waste deposit and continue for occur over a long period, based on the model set by the NGER (Measurement) Determination. Based on this Methodology, in, for example, a Victorian landfill that accepted an equal quantity of waste during the carbon tax years, only 2.3% of the emissions would have arisen during those years. Therefore, 97.7% of the emissions arising subsequently in an offsets-reporting period should be considered non-additional. More detail on the non-carbon tax is provided in section 2.5.2.

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[5] Parameter “DE” in Equation 7 of the Methodology.

Under the carbon tax, many landfill facility operators charged their customers in relation to future carbon liabilities that were expected to accrue as the waste being deposited decayed over many decades. With repeal of the tax, future tax liabilities for emissions from that waste will not eventuate, although charges equivalent to those future year liabilities were paid by many waste customers.

2.2.4 Baselines

Different landfill gas projects may receive different baselines. The baseline applied to a project is the main factor when assessing the risk of under- or over-crediting. If a baseline is too high, a project would not be credited ACCUs for abatement additional to regulatory requirements, and may mean the project does not go ahead. By contrast, if a baseline is too low, a project will receive ACCUs for abatement that would have occurred regardless because of regulatory requirements.

Section 28 of the Methodology sets a baseline for new or recommencing projects, equal to the greater of the regulatory proportion or a default value. It is noted that projects that transitioned from the Greenhouse Friendly program and the NSW Greenhouse Gas Reduction Scheme (GGAS) were allowed to maintain their original baselines, 0% and 24% respectively.

2.2.4.1 The regulatory proportion

The regulatory proportion is calculated with reference to Schedule 1 of the Methodology, which provides four options:

1. Reference to state or territory guidelines for landfilling, which are interpreted as setting limits for gas concentrations above the landfill. These levels are linked to a percentage gas capture rate through modelling. The modelling links methane generation (calculated using NGER methods) to concentrations above the landfill, using a model based on landfill surface area and the proportions of the surface area under different types of cover.
2. Asking the regulator what gas capture rate is needed to comply.
3. Asking the regulator whether the current gas capture rate is compliant.
4. Determined by an independent expert.

Despite not been able to assess the source of information for option 1, the input assumptions parameters appear to be appropriate.

2.2.4.1.1 Do landfill operators regularly exceed the regulated concentrations of methane?

Interviews with relevant State regulatory authorities were undertaken. SMEC contacted the Victorian EPA regulator who confirmed that landfills in their jurisdiction are required to monitor and report on compliance on a yearly basis. Unfortunately, data on exceedances is not available but suggested to review the landfills' annual performance statements in the EPA Interaction Portal[6]. Additionally, the EPA Victoria provided a list of 69 landfill licences numbers.

[6] Information obtained from the EPA Interaction Portal accessed on 12 September 2017 from: https://portal.epa.vic.gov.au/irj/portal/anonymous?NavigationTarget=ROLES://portal_content/epa_content/epa_roles/epa.vic.gov.au.anonrole/epa.vic.gov.au.searchanon&trans_type=ZAPS

SMEC performed a review of the yearly performance statements (comprising of reports from years 2013 to 2016). The focus was on compliance with licence condition requirement L5. The requirement reads:

> *"You must prevent emissions of landfill gas from exceeding the investigation levels specified in Best Practice Environmental Management, Siting, Design, Operation and Rehabilitation of Landfills (EPA Publication 788)".*

A summary of the yearly compliance is provided in Table 2 and a detailed outline in Appendix G. In summary, only 40% of the landfill sites in Victoria comply with L5 licence condition requirement. Most of the exceedances were noted to be a single instance where readings exceeded the requirements. It was also noted that exceedances were either from methane and / or carbon dioxide.

Table 2: Victorian landfill licences compliance with L5 condition requirement

Compliance with L5 condition requirement	2013	2014	2015	2016
Yes	17	14	15	18
	43%	*35%*	*38%*	*45%*
No	21	25	25	21
	53%	*63%*	*63%*	*53%*
Compliance report not available (for a particular year)	2	1	0	1
	5%	*3%*	*0%*	*3%*
Subtotal compliance report available	40	40	40	40
	58%			
No result for the licence	29	29	29	29
	42%			
Total licences	69	69	69	69

2.2.4.2 The default baseline value

The default baseline value is 0% if the landfill has not been subject to legislation or guidelines for gas collection, and 30% otherwise. It is noted that the baseline of 30% is applied to the landfill gas captured and combusted, not to the larger quantity of landfill gas generated (refer to section 6.2.2.5). It is understood that there are few sites where the 0% baseline has been determined to apply for new projects, so the 30% default baseline generally applies.

In practice, where a State or Territory requires landfill gas management (refer to section 2.4), the extent of landfill gas capture required at a particular site varies widely and depends on:

1. The results of monitoring of gas concentrations above the landfill surface, within monitoring bores, at the site boundaries and/or within underground services close to the site;
2. The distance to the nearest 'sensitive receptors' (e.g., houses);
3. The extent to which odour complaints have been received;
4. The extent of recent rainfall; and
5. The degree of enforcement rigour being applied by the local regulator.

Often gas capture is implemented for the first time as part of an ERF project (or before the ERF; GGAS or an electricity generation project). An analysis of the ERF Project Register on 9 October 2017 shows 19 new and only seven (7) upgrade landfill gas projects.

Large landfills close to highly urbanised areas are at higher risk of giving rise to odour complaints, and are consequently likely to be subject to stricter levels of regulatory enforcement. Wet periods can lead to pulses of gas and odour which are not predicted by NGER modelling. Landfills that are owned by local governments – the norm in regional areas – may be subject to community expectations in terms of odour management so that State enforcement is of secondary consideration.

Because of the inherited variability between sites, the 30% default baseline cannot, in practice, be considered accurate for all sites. However, there is a need for one or more default values.

We are advised by the DoEE that the 30% default baseline was supported by modelling by GHD Australia Pty Ltd (GHD) using relevant values in State and Territory regulations (such as upper limits for methane emission rates from landfill surfaces), and some draft information from that review is available. We are also informed it was also a compromise value agreeable to both the DoEE and the industry. Based on our industry experience, it represents a reasonable and conservative average.

This issue could be investigated at greater depth. It is anticipated that the best way to assess the appropriateness of the 30% regulatory default would be to:

- Compare site gas capture rates (through NGER data) with State and Territory advice on levels of compliance, to the extent this is available. This would highlight the extent of compliance with gas management requirements; or
- Consider the different State and Territory regulatory requirements to determine a State/Territory-specific baseline percentage; or
- Measure the accuracy of a default 30% baseline (i.e. regulatory requirements might represent a different percentage).

2.2.4.3 Case study – why are there few new landfill gas projects in Victoria?

Victoria's best practice environmental management guideline[7] sets default landfill gas action levels (summarised in Table 3). The action level includes 100 ppm methane concentration above the landfill's final cap. This has been interpreted in the Methodology as the basis for the regulatory limit.

The guideline states (p.33) that "EPA need not be advised of an excursion above an action level where only an onsite location was affected and the matter is rectified within 24 hours".

As noted by the DoEE, where an exceedance occurs and is rectified within 24 hours, the exceedance will have an immaterial effect on the calculations for the whole reporting period. Therefore, the Methodology's approach would appear to be reasonable.

[7] EPA Victoria, Best Practice Environmental Management Guide, "Siting, design, operation and rehabilitation of landfills" (2015), retrieved on 1 August 2017 from www.epa.vic.gov.au/~/media/Publications/788%203.pdf

Table 3: Victoria Best Practice Environmental Management - Landfill gas action levels (partial)

Location	Parameter(s)	Action level / unit
Landfill surface final cap	Methane concentration in air*	100 ppm
Within 50mm of penetrations through the final cap	Methane concentration in air**	100 ppm
Landfill surface intermediate cover areas***	Methane concentration in air*	200 ppm****

Notes:

* Point of measurement is 50mm above the landfill surface.

** Point of measurement is 50mm from the point of discharge.

*** Intermediate cover areas are those that do not have an engineered landfill cap and are not scheduled to receive waste during the next three months.

**** This value is inconsistent with the Measurement Determination, which indicates a value of 100 ppm. The value may have been 100ppm before revision.

The landfill gas action levels in the Victorian (and the ACT) guidelines are relatively low – other jurisdictions have limits of 500 ppm or no limit at all. As such, applying these action levels to the Methodology as methane concentration limits has resulted in few new ERF projects in Victoria.

2.2.4.3.1 Illustrative example

The effect is illustrated through a comparative theoretical analysis (refer to Appendix I) of the regulatory proportion in each jurisdiction for a landfill that:

- opened in 2000.
- accepted 100,000 tonnes in each year comprising 40% MSW (class 1), 40% C&I and 20% C&D.
- is wholly covered with final cover.

The NGER solid waste calculator (2016-17 version) was used to derive emissions (if no gas capture):

- QLD, NT (fast degradation rates): 91,887 tCO_2-e
- NSW (intermediate degradation rate): 85,831 tCO_2-e
- ACT, SA, TAS, VIC, WA (slow degradation rate): 60,721 tCO_2-e

Schedule 1 4(2) of the Methodology sets out the allowable flux rate for final cover in each state and territory (corresponding to methane concentration limits) of:

- ACT, VIC: 0.3×10^{-6} $tCH_4/m^2/hr$
- NSW, QLD, TAS, WA: 2.5×10^{-6} $tCH_4/m^2/hr$
- NT, SA: N/A

Three scenarios have been considered in which the site area is 40, 20 or 10 hectares. Using equation 22 of the Methodology, the permitted annual methane flux for each scenario and each jurisdiction has been calculated as shown in Table 4.

Table 4: Permitted annual methane flux (t CO_2-e) for each scenario and jurisdiction

State \ Scenario	40 ha site	20 ha site	10 ha site
NSW, QLD, TAS, WA	243,333	121,667	60,833
ACT, VIC	29,200	14,600	7,300
NT, SA	no limit	no limit	no limit

Comparing these values with the estimated emissions without gas capture given above, the regulatory proportion in each State and Territory was calculated, as shown in Table 5.

Table 5: Regulatory proportion for each scenario and jurisdiction

State \ Scenario	40 ha site	20 ha site	10 ha site
ACT	52%	76%	88%
NSW	-	-	29%
NT	-	-	-
QLD	-	-	34%
SA	-	-	-
TAS	-	-	-
VIC	52%	76%	88%
WA	-	-	-

Equation 13 in the Methodology outlines that the applicable baseline is the maximum of the regulatory proportion and the default value. Assuming the default value of 30% applies in all States and Territories, then the applicable baselines are as shown in Table 6.

Table 6: Applicable baseline for each scenario and jurisdiction

State \ Scenario	40 ha site	20 ha site	10 ha site
ACT	52%	76%	88%
NSW	30%	30%	30%
NT	30%	30%	30%
QLD	30%	30%	34%
SA	30%	30%	30%
TAS	30%	30%	30%
VIC	52%	76%	88%
WA	30%	30%	30%

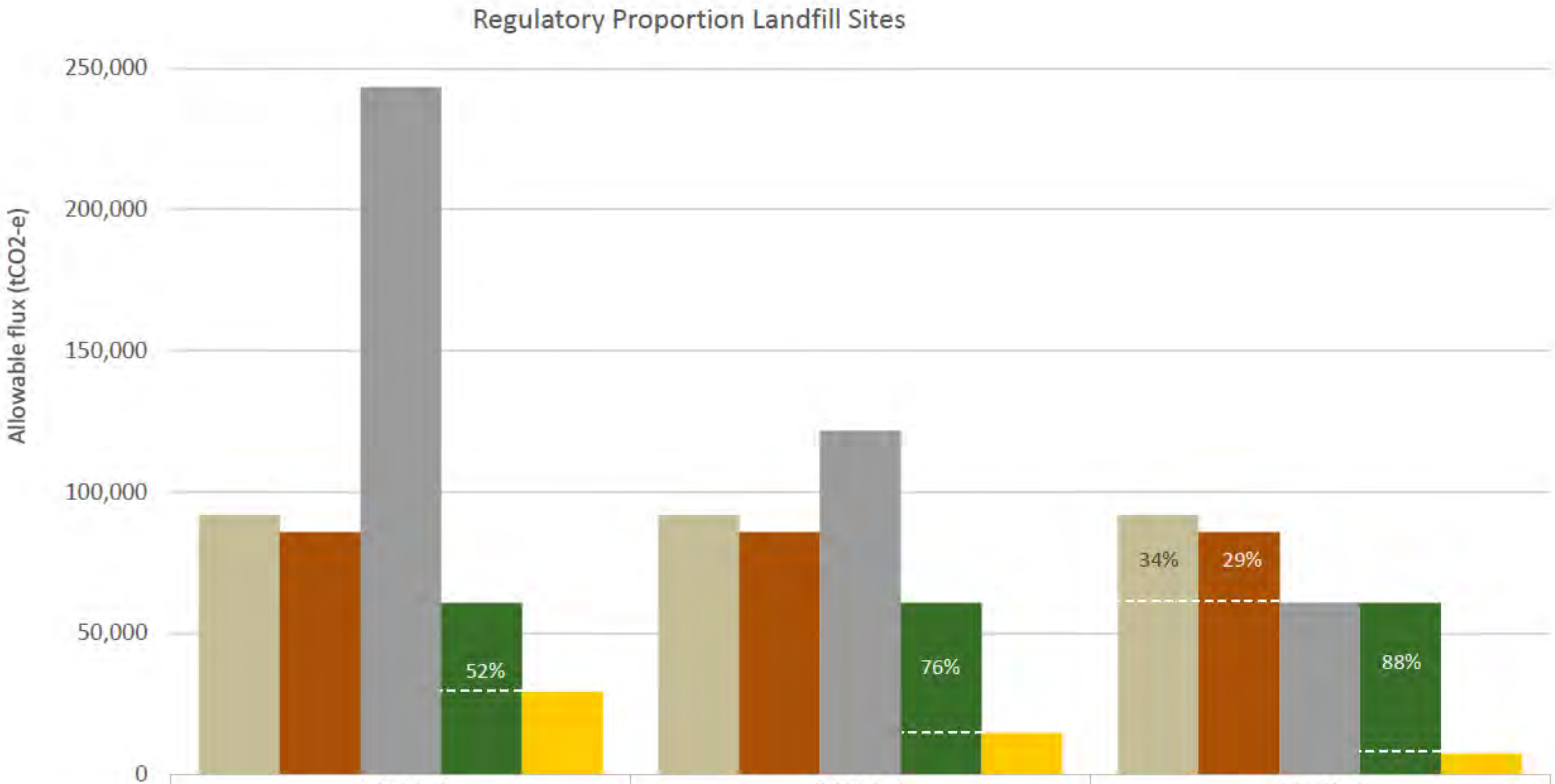
It is noted that the baselines are higher in Victoria (and the ACT) than any other state, which disincentivises ERF landfill gas projects. It is noted that the ACT has identical baselines to Victoria but has only one operating landfill which already captures high levels of landfill gas. The ACT is therefore unaffected by its high baseline.

To illustrate the above-mentioned scenarios, Figure 2 is provided. The estimated annual emissions are provided and the Allowable Flux for QLD, NSW and VIC. There the Allowable Flux is less than the estimated annual emissions, the difference between them is highlighted (as a percentage). This is, for scenario A,

- the allowable emissions for QLD and NSW are 243 ktCO_2-e and the annual estimated emissions are 92 ktCO_2-e for QLD and 86 ktCO_2-e for NSW. Consequently, there is no regulatory proportion for these sites; and
- the allowable emissions for VIC are 29 ktCO_2-e and the annual estimated emissions are 61 ktCO_2-e. The difference (for what a landfill site could claim ACCUs under the ERF) are 31.5 ktCO_2-e (which accounts for 52%). This represents the regulatory proportion, as indicated in Table 6.

Conclusion 3 Tighter (i.e. lower) landfill gas action levels in Victoria (and the ACT) create a higher regulatory proportion, modelled as 52%-88% depending on the landfill size. As such, in these cases, the regulatory proportion is higher than the default baseline of 30% (for non-transitioning projects). The Methodology says therefore, the regulatory proportion needs to be selected as the site's baseline.

Conclusion 4 The current Methodology approach to calculating abatement seems appropriate. It is noted that the default baseline of 30% (for non-transitioning projects) of landfill gas collected and combusted (not gas generated) was negotiated between the government and the industry in 2011. There has not been a subsequent operational data review and re-calculation will require a more thorough investigation. It is expected that amongst others, the geographical location (a factor in the organic decomposition rates, and hence the landfill gas generation rates) would be considered.



	A (40 ha)	B (20 ha)	C (10 ha)
QLD Emissions	91,887	91,887	91,887
NSW Emissions	85,831	85,831	85,831
Allowable Flux (QLD & NSW)	243,333	121,667	60,833
VIC Emissions	60,721	60,721	60,721
Allowable Flux (VIC)	29,200	14,600	7,300

Figure 2: QLD, NSW & VIC landfill sites – allowable emissions (baseline representation)

2.3 Assessment of other government programs and financial incentives on the decision to undertake landfill gas capture and combustion at a landfill site.

Summary:

- *Most government programs address waste diversion, not landfill gas capture.*
- *Other financial incentives associated with landfill gas capture and combustion are:*
  - *the sale of electricity generated; and*
  - *the creation and sale of Large Scale Generation Certificates.*

There are multiple State-based and local government incentives for diverting organic waste from landfills, but apart from the ERF there are negligible, or no, similar incentives to capture landfill gas. Pre-existing programs such as 'Greenhouse Friendly', the NSW GGAS and the Carbon Farming Initiative (CFI) have been folded into the ERF. The main complementary government program that landfill gas projects can access is the revenue from the generation and sale of electricity and associated Large Scale Generation Certificates (LGCs).

Landfill gas projects can be divided into two types:

- *Flaring projects*, where landfill gas is collected to combust it. This type of project typically occurs at smaller landfills, sites which are far from the electricity grid, younger sites that are not yet generating much gas, or older sites that are largely depleted of gas (refer to section 2.3.1).
- *Energy generation projects*, typically (in Australia) involving feeding the collected landfill gas into a gas reciprocating engine generator that is connected to the electricity grid. This typically occurs at large sites over the bulk of their landfill gas generating life (refer to section 2.3.2).

2.3.1 Flaring projects

Capital costs for a flaring project would typically be in the hundreds of thousands of dollars (refer to section 6.3 for additional information.) For these projects, there is no other source of revenue to collect gas other than the ERF. If an ERF flaring project was no longer eligible and the landfill was not obliged to capture gas by the State or Territory regulator or local community expectations as explained in section 2.2.4.2, it could be expected the gas capture and flare system to degrade and cease operation. This is because:

- Landfills contain biologically active putrescible waste and landfill gas is wet, corrosive, and contains traces of remnant putrescible waste. Because of this, the equipment degrades and requires ongoing maintenance to maintain its adequate operation; and
- Landfills are typically constructed in discrete 'cells' that are progressively established across the site. Landfill gas production moves with the landfilling, so new bores need to be regularly established. Without an incentive to establish new bores, the flaring system would be likely to deplete the gas from the current operational cells and then close.

Some sites with flares may continue flaring due to regulator pressure or community expectations. These sites could be expected to do the minimum to achieve these ends. This is likely to represent a reduction in gas capture levels under the ERF, which incentivises capture and destruction of each tonne of methane.

2.3.2 Energy generation projects

The costs for energy generation projects greatly exceed those for flaring. Capital costs for the reciprocating engines are typically AUD$1.8m per megawatt electrical (MWe) (refer to section 6.3). As the power generation engines are modular (i.e. additional power generation engines are installed as the gas build-up allows for their operation), the costs are predominantly linearly scalable. It is noted that most of the projects are implemented in a staged manner. In consideration of additional required electrical infrastructure (i.e. connection systems), these costs could escalate to ~AUD$2.5m per MWe.

The sale of electricity and LGCs provides an incentive for electricity generation which will vary by site and on the stage of the landfill (or project) lifecycle. Specific project data could not be obtained as this information is not public and the project owners were not willing to share the details. Nevertheless, to illustrate how the value of ACCUs relate to the total project income, a high-level assessment was performed. These figures consider the most recent estimate (i.e. 2017) and a 2013 estimate. The 2013 estimate was selected for illustrative purposes and it is noted that this period was when compliance ACCUs had a fixed price.

2.3.2.1 'Bundled' Power Purchase Agreements consideration

To assess how the incentives correlate given the volatility in price, the electricity and LGCs values were 'bundled'. These incentives covered both electricity and LGCs, which are based on long term power purchase agreements (PPAs). It is noted that the PPAs value has been declining. Figure 3 shows that these prices have approximately halved since projects commenced in 2012.

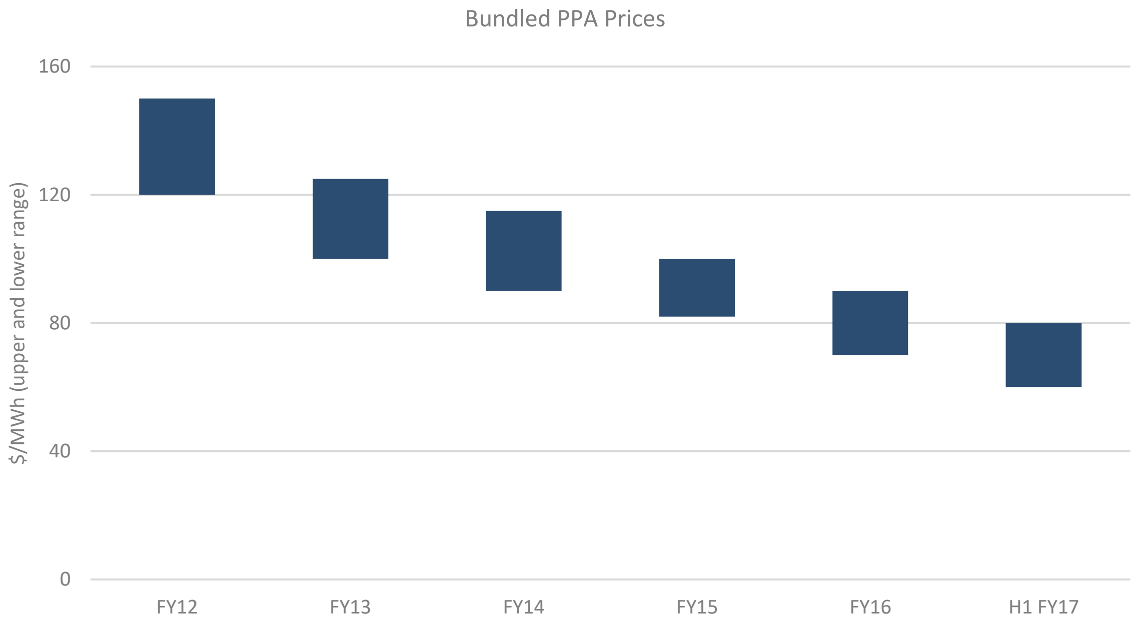


Figure 3: Annual trend, PPA prices[8]

[8] Vorrath, S. and Parkinson G. (2017), "Origin signs up for 200MW solar plant in S.A, as PPA prices tumble", retrieved from http://reneweconomy.com.au/origin-signs-up-for-200mw-solar-plant-in-s-a-as-ppa-prices-tumble-86240/

2.3.2.1.1 Upper and lower price scenarios

To assess how the incentives vary, given the upper and lower values provided in Figure 3, two scenarios were considered. The scenarios consider the upper and lower bundled LGC costs, whilst the value of ACCUs was not varied. The analysis considers a site with a 30% baseline, 33% efficient engines and the following constant estimated financial incentives:

- The ACCUs price (noting that each ERF contract has a unique and confidential price) for both high and low scenarios considered:
  - For the most recent estimate (2017): $11 per ACCU; and
  - For 2013: $23 per ACCU. It is noted that during this period, compliance ACCUs had a fixed price at first of $23.00, and then $24.15.
- The following 'bundled' PPA values were considered:
  - For the most recent estimate (2017):
    - The low scenario considered $60 per MWh (recent large projects sold at ~ $55[9] to $65[10] per MWh); and
    - The upper scenario considered $80 per MWh.
  - For the 2013 estimate:
    - For the low scenario $100 per MWh was considered; and
    - The upper scenario considered $120 per MWh.

The results are provided in Table 7 and graphically presented in Figure 4 and Figure 5.

Table 7: Estimated Financial Incentives (2017 and 2013)

Estimated Financial Incentives	2013 estimate		Latest (2017) estimate	
	Low Scenario	High Scenario	Low Scenario	High Scenario
ACCUs	44%	39%	39%	32%
Electricity generated and LGCs 'bundled'	56%	61%	61%	68%

[9] Origin PPA $50-$60 http://reneweconomy.com.au/origin-stuns-industry-with-record-low-price-for-530mw-wind-farm-70946/
[10] AGL Silverton windfarm at $65 http://reneweconomy.com.au/agls-new-200mw-silverton-wind-farm-to-cost-just-65mwh-94146/

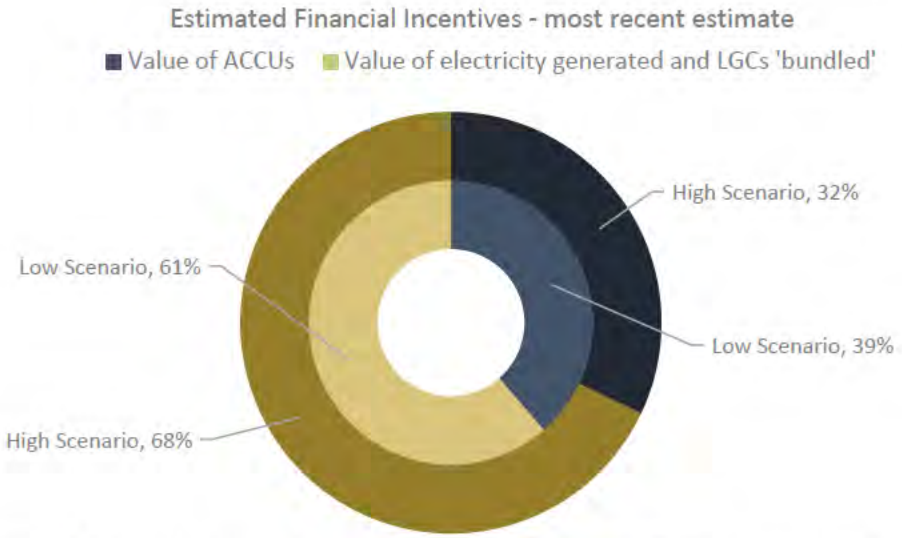


Figure 4: Estimated Financial Incentives – Energy Generating Project – most recent estimate

As highlighted in Figure 4 using this data, the sale of ACCUs at present (2017) represents approximately 39% in the low scenario and 32% in the high scenario of the financial incentive of the project. A summary of the calculations is provided in Appendix F.

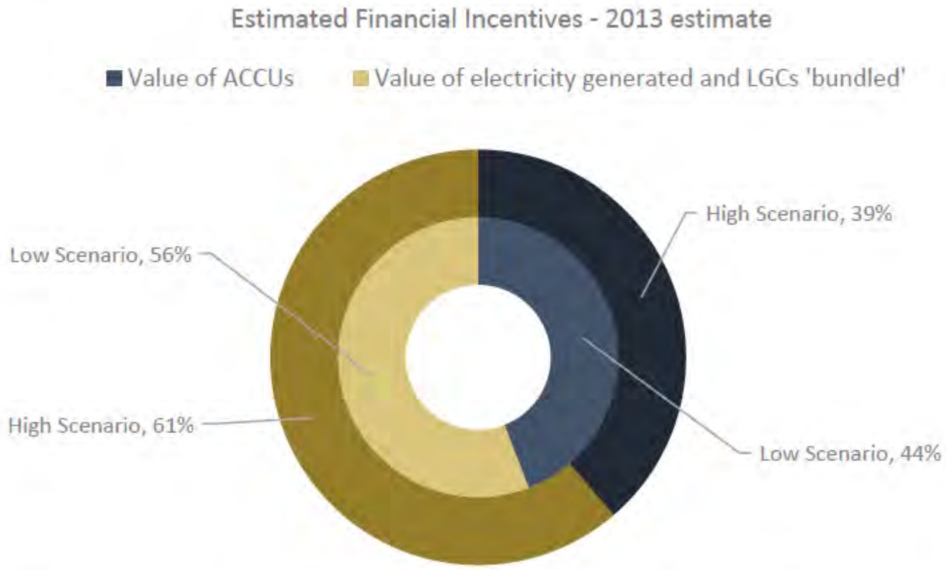


Figure 5: Estimated Financial Incentives – Energy Generating Project – estimate for 2013

Conversely, Figure 5 highlights that the sale of ACCUs estimated using 2013 values, the ACCUs would represent approximately 44% in the low scenario and 39% in the high scenario.

2.3.2.2 Sensitivity of the value of ACCUs

To consider the variance and sensitivity of the value of ACCUs, the following assessment was undertaken. The most recent estimates (2017) – low scenario details were considered. The value of the 'bundle' PPA was fixed at $60 per MWh. The value of ACCUs was varied from $15 to $8 per ACCU. The results are shown in Figure 6.

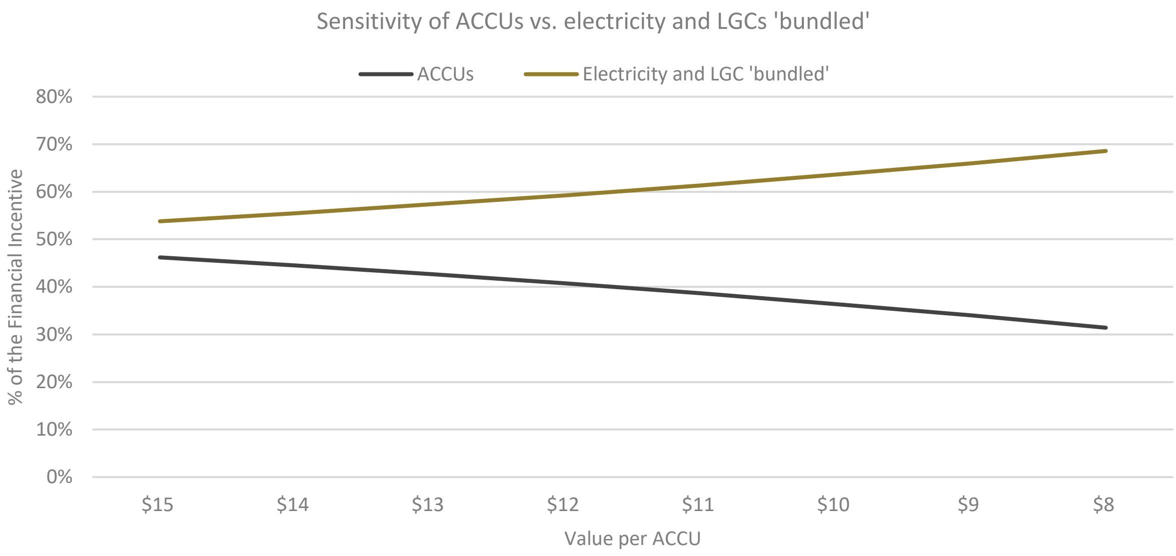


Figure 6: ACCUs sensitivity vs 'bundled' PPA

As shown in Figure 6, a price of $15 per ACCU would represent approximately 46% of the financial incentives of a project. Similarly, a price of $8 per ACCU would represent approximately 30%. This correspond to a 2 or 3% variance in the financial incentive for every dollar varied in the ACCU price. More information on the financial performance is provided in section 6.3.

2.3.2.3 Relation between the value of ACCUs and the abatement

This section explores the potential impact of ACCU income on the volume of landfill gas destroyed. Figure 7 shows the annual trend since 1990 for both flare and electricity projects combined. The following periods are highlighted:

- From 1990 to 1995 there is a small increase (i.e. from an almost zero baseline in the amount of landfill gas destruction to nearly 1,000 ktCO_2-e).
- From 1995 to 1998 there is a steep increase of nearly 2,000 ktCO_2-e in abatement. This increase is driven presumably mainly by the ability to sell electricity. Also, other factors may be the odour regulations, guidelines and community concerns and the introduction of 'green' tariffs in some States and the Renewable Energy Target (RET) in 1997.
- From 1998 to 2002 the growth appears to level off, until 2003 when the GGAS scheme was introduced.
- In 2003, a significant increase in capture rates occurred, until another flat period from 2005 when GGAS prices and regulatory certainty 'stalled' during CPRS (carbon tax) discussions, until the introduction of the CFI and carbon tax in 2011.
- The growth stalled with the loss of the carbon tax value in 2014.
- The commencement of ERF auctions in 2015 continued to marginally increase recovered GHG emissions.

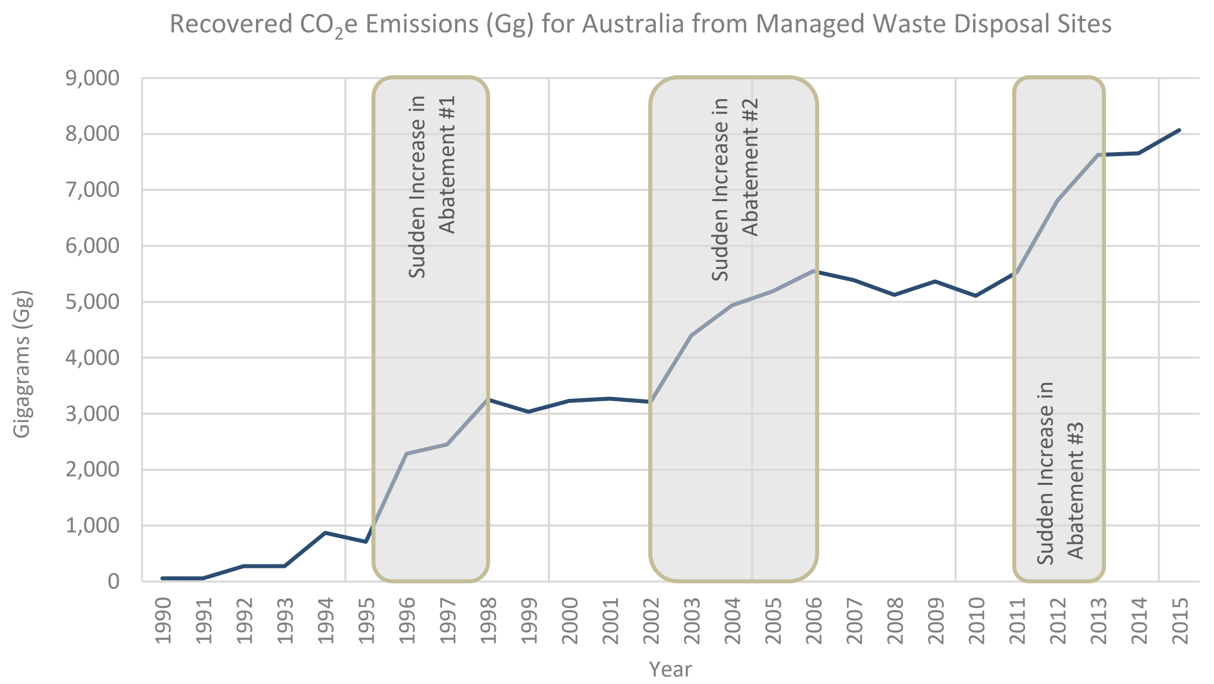


Figure 7: Annual trend, emissions reductions at landfill sites[11]

It is noted that two types of drivers have been identified that may have influenced the GHG emissions abatement, these are:

- Sudden changes: three sudden changes can be perceived as indicated in Figure 7. As highlighted above, these changes coincide with:
  - Financial drivers, such as:
    - Ability to sell electricity in 1995;
    - GGAS introduction in 2003; and
    - Carbon tax introduction in 2011.
- Gradual changes: other drivers that may influence the abatement of GHG emissions, albeit in a more gradual manner (i.e. cannot be pinpointed in Figure 7) are:
  - Regulations; whilst no specific requirements of the abatement required, the introduction of State and Territory regulation affects the amount abated;
  - Community complaints / concerns over odour;
  - Other incentives:
    - Modular power generation technology (i.e. technology improvement / cost decrease of power generation and flaring equipment);
    - Landfill management intent (including reputational benefits, environmental values, quality objectives and susceptibility to public perception);
    - Health and safety issues or concerns (including impacts to the environment, human health and amenity); and
    - Risk Management (e.g. mitigate asphyxiation, explosion and migration potential).

[11] Department of the Environment and Energy, National Greenhouse Gas Inventory, "Recovered CO_2e Emissions (Gg) for Australia from Managed Waste Disposal Sites". Retrieved from: http://ageis.climatechange.gov.au/Chart_KP.aspx?OD_ID=70067876761&TypeID=2

In summary, it appears that landfill gas destruction volumes have increased when incentives for methane destruction are present (particularly when there are financial incentives present), and have stalled (and even decreased as highlighted in the period 2006 to 2010) when they are absent.

As noted in section 6.3.2.1, Table 27 shows that the availability of financial incentives for GHG emissions abatement results in revenue (for both; flare and electricity generation projects) in consideration of the life of asset (considered to be 7 years in accordance with the ERF contracting period). Furthermore, the absence of these incentives results in a cost to the site despite the revenue from the electricity generation and the renewable energy certificates.

Conclusion 5 The establishment of most landfill gas collection systems correlates with the introduction of financial incentives from the creation of GHG emissions abatement and/or the generation of electricity. Gas collection in 2015 was 2.5 times (8,070 $ktCO_2$-e in 2015 versus 3,210 $ktCO_2$-e in 2002) than before incentives (beyond the value of electricity) were introduced in 2003. These incentives appear to drive and maintain investment in landfill gas collection. Without them, investment is likely to commence later in the lifecycle of cells and be lower, leading to collection rates declining in existing projects. This conclusion is more certain in relation to landfill gas flaring but also applies to energy generation projects.

2.4 Whether projects/activities covered by the method are required to be carried out by, or under, a law of the Commonwealth a State or Territory.

Summary:

Regulations of landfills follow a tiered approach:

i. *State legislation and regulation,*
ii. *Landfill guidelines, and*
iii. *Site-specific licences.*

The focus, regulation and enforceability of requirements vary across Australia. There is no explicit indication in the regulations of how the size of a landfill and its proximity to population centres effects gas capture requirements.

Note:

Based on the assessment of the requirements of this section, parts (i) and (ii) (as stated below) are interrelated and reference each other constantly, consequently, the assessment has focused on both parts together:

i. *When addressing this part of the criterion the Service Provider will assemble and provide information on regulatory requirements (including guidelines, regulations or other policy) for landfill gas capture and combustion for each State and Territory and evaluate how these translate into actual gas capture requirements on-site.*
ii. *The Service Provider will undertake an analysis of licence requirements for waste disposal activities. The analysis will examine the extent to which landfills are required to capture landfill gas and how this differs between States or Territories and landfills of different sizes and proximity to population centres.*

2.4.1 Legal structure under which most landfills operate

Landfills typically operate under a three-tier legal structure. This structure provides the framework of requirements and includes:

- Overarching legislation and regulatory requirements (section 2.4.1.1),
- Landfill guidelines (section 2.4.1.2), and
- Site specific landfill licences (section 2.4.1.3).

As noted above, in the Methodology, the default baseline value is 0% if the landfill has not been subject to legislation or regulatory guidelines for gas collection, and 30% otherwise. It is understood that there are few sites where the 0% baseline has been determined to apply for new projects. Consequently, the 30% default baseline generally applies.

2.4.1.1 Overarching Legislation and Regulation

There is no overarching federal legislation that governs the operations of landfills. Each State and Territory has its own set of legislation and regulations that set binding requirements on landfills (refer to Appendix A for an exhaustive list).

These binding requirements are general in nature, and mostly relate to the State-based Environmental Protection Acts. Emphasis is made in the regulations requiring the general provision that "environmental harm shall not occur" (i.e., a person shall not pollute or reduce local environmental amenity).

In Victoria, as an example, the Siting, Design, Operation and Rehabilitation of Landfills document[12], which is subservient to the Environment Protection Act, states that the "authority may require a landfill operator to install a landfill gas collection system". As with other States, this provision relates to a risk management activity (e.g. odour, toxicity and explosion risk). This provision has driven the installation of capture and combustion devices (i.e. flaring and power generation systems) as there are financial incentives available (e.g. sale of ACCUs, electricity generation and/or LGCs). It is noted that other activities could be implemented that meet the provision without having nearly as much impact on the GHG abatement, such as:

- Better capping material that reduce the rate of direct emissions of landfill gas;
- Improved lining to prevent uncontrolled movement of landfill gas through the base and sides of the landfill site;
- Improved leachate management and control of rainwater ingress; and
- Gas pressure management (i.e. reduction of built-up gas pressure by increasing gas extraction).

<u>Conclusion 6</u> Legislative or regulatory requirements specifically requiring landfill gas capture at landfills relate primarily to risk management activities (e.g. odour, toxicity and explosion risk), rather than GHG emissions abatement activities. Management tools other than collection/flaring, such as better capping materials, could achieve legislative compliance but at a lesser rate of GHG emissions abatement.

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[12] EPA Victoria (2015), Siting, design, operation and rehabilitation of landfills. Retrieved on 1 August 2017 from http://www.epa.vic.gov.au/~/media/Publications/788%203.pdf.

2.4.1.2 General Policy and Guidelines

Each State and Territory[13] has developed its own specific set of guidelines (refer to Appendix B for details). The guidelines are designed to:

- Provide guidance and set aspirational targets of how an optimal landfill should operate; and
- Assist landfills meet specific State or Territory environmental objectives.

Guidance and licence requirements on landfill gas management are considered in two broad categories:

A. *General requirements* to minimise or control gas emissions and odour; and
B. *Specific requirements* to prevent gas concentrations above the landfill surface exceed specified levels.

Some guidelines such as those in New South Wales[14] (page 31) and South Australia[15] (section 8.3) do specifically mention GHG emissions minimisation. However, the documents focus on other environmental and safety issues such as odour and methane concentrations at the boundary of the site.

New South Wales and Victoria's guidelines refer to the UK's Guidance on the Management of Landfill Gas (LFTGN 03). The Guidance requires a risk assessment focusing on the "potential impacts on local environment, health and amenity" (p. 17). As such, the potential impacts relate to nearby receptors and potential gas migration pathways. As these requirements are site-specific, it is not possible to provide a robust general formula that translates these requirements into a universal numeric gas capture rate. Nonetheless, some gas collection advice is provided for example:

- that an active gas extraction system be designed to achieve the maximum practicable collection efficiency (85% suggested); and
- that a methane flow rate exceeding 50-100 cubic meters is an indication that a gas extraction system is required.

There are specific requirements that relate to the size of the landfill (e.g. Tasmania's requirement applies for sites that exceed 20,000 tonnes per annum in any three consecutive years – refer to 2.4.1.3.1.7). Furthermore, it is noted that larger landfill sites are normally better placed to install electricity generation engines due to economic practicability and landfill gas availability.

Conversely, specific requirements related to proximity to population were not found. Nevertheless, the landfill's proximity to population will have a higher risk factor (e.g. health and safety, odour complaints, etc.) and may result in specific site restrictions.

Table 8 provides a summary of the specific and general requirements, including the stipulated threshold concentration levels. If the threshold concentration levels are exceeded, certain actions are triggered. It is noted that should a landfill fail to meet its surface emissions test, it is generally cause

[13] Apart from the ACT which has adopted Victoria's Best Practice Guidelines.
[14] NSW EPA, Environmental Guidelines: Solid waste guidelines, second edition, 2016
[15] SA EPA Guidelines, Environmental management of landfill activities (municipal solid waste and commercial and industrial general waste), January 2007

for repeated, more frequent testing and not necessarily an automatic matter for penalty. Individual regulators will follow their own risk based education and enforcement procedures.

Appendix D summarises the exceedance responses across the States and Territories, also refer to Table 2 in section 2.2.4.1.1 for a record of compliance in Victoria.

Conclusion 7 Landfill gas capture is mentioned in State and Territory guidelines on appropriate landfill management. Nevertheless, these guidelines focus on potential environmental and health and safety risks such as; methane concentrations at the boundary of the site, odour and potential impact on receptors and potential gas migration pathways. Landfill gas combustion seems to be the most effective (and given the financial incentives), the most economical means to address these requirements. Nevertheless, landfill sites might implement other activities (refer to section 2.4.1.1) that will result in compliance with the guidelines without the abatement of GHG emissions.

Table 8: General and specific requirements for landfill gas management

Item	Parameter	States / Territories with specific requirements			States / Territories with guidance thresholds (enforcement by some States under site specific licence conditions)				
		NSW	VIC	QLD	SA	TAS	NT	WA[16]	ACT
Landfill surface final cover[17]	Methane	500 ppm	100 ppm	500 ppm	No limit	500 ppm	No limit	Under review	-
Within 50mm of penetrations through the final cap[5]	Methane	NA	100 ppm	NA	NA	NA	-	Under review	-
Landfill surface intermediate cover areas[18]	Methane	500 ppm	**200 ppm**[19]	500 ppm	NA	500 ppm	-	-	-
Within immediate vicinity of penetrations through intermediate cover[5]	Methane	NA	1000 ppm	NA	No limit	NA	No limit	Under review	-
Subsurface geology at the landfill boundary	Methane and carbon dioxide	1% v/v CH_4 and 1.5% v/v CO_2 above background	1% v/v CH_4 and 1.5% v/v CO_2 above background	25% LEL	1% v/v CH_4 and 1.5% v/v CO_2 above background	1.25% v/v CH_4	1% v/v CH_4 and 1.5% v/v CO_2 above background (where buildings are within 250m of site)	Under review	-
Subsurface services on and adjacent to the site	Methane and carbon dioxide	1% v/v CH_4 (within all buildings and other enclosed structures with 250m of deposited waste)	10,000 ppm	25% LEL	1% v/v CH_4 and 1.5% v/v CO_2 above background	1.25% v/v CH_4	-	Under review	-

[16] Current requirements reference the UK's Construction Industry Research and Information Association (CIRIA) C665. However, WA is currently reforming its regulatory framework.

[17] Point of measurement is 5cm from surface or point of discharge.

[18] Intermediate cover areas are those that have not reached final profile and are not scheduled to receive waste during the next three months.

[19] This value is inconsistent with the Measurement Determination, which indicates a value of 100 ppm. The value may have been 100ppm before revision.

Item	Parameter	States / Territories with specific requirements			States / Territories with guidance thresholds (enforcement by some States under site specific licence conditions)				
		NSW	VIC	QLD	SA	TAS	NT	WA[16]	ACT
Buildings/structures on and adjacent to the site	Methane and carbon dioxide	1% v/v CH_4 (within all buildings and other enclosed structures with 250m of deposited waste)	5,000 ppm	25% LEL	1% v/v CH_4 and 1.5% v/v CO_2 above background	-	1% v/v CH_4 and 1.5% v/v CO_2 above background (where buildings are within 250m of site)	Under review	-
Landfill gas flares	Volatile organic compounds (excluding methane)	Gas residence time >0.6 s, Combustion temp >760°C, 98% destruction efficiency Emissions from landfill gas combustion must not exceed concentration limits in the POEO (Clean Air) Regulation 2010	98% destruction efficiency	-	98% destruction efficiency Control of combustion emissions to comply with the Environment Protection (Air Quality) Policy 1994 (updated 2016)	-	-	-	-
Bio filters	Methane flux	-	1.0g/m²/hr	-	-	-	-	-	-
Regulatory / Guidance document		NSW EPA Guidelines / Licences	VIC BPEM Guidelines / Licences	ERA 60	SA EPA Guidelines (enforcement is site specific - development applications and / or licences)	TAS EPA Guidelines	NT EPA Guidelines		

2.4.1.3 Specific Landfill Licence Requirements

Licences set out site-specific requirements, breaches of which can typically attract immediate fines or prosecutions. Historically, landfill licences were often tailored to a site but recently, New South Wales and Victoria have moved towards more generic licencing that refers to landfill guidelines, adopting a risk-based approach to licensing requirements (refer to Appendix C for general licence requirements).

Requirements related to the capture of landfill gas are present in some licences, however specific requirements (e.g., the percentage or volume of landfill gas capture required) are not mandated. New South Wales and Victoria's licences reference best practice guidelines, which also do not specifically require some absolute or proportional quantity of gas capture.

2.4.1.3.1 Licence review methodology

An online review of publicly available landfill licences was undertaken as part of the engagement. The number of licences retrieved and reviewed are summarised in Table 9. For each licence consulted, the requirements related to the landfill gas were summarised in a spreadsheet. This spreadsheet has been provided as Annex A. A thorough review of these requirements was undertaken and a summary of the requirements was made. The summary is provided in Appendix C. Key notes for each State are provided in the below sections and a sample of the licences consulted is provided in Annex B.

Table 9: Landfill gas licence requirements reviewed by State

State	Section	Current (estimated) no. sites[20]			No. of licences reviewed		
		Landfill	Multi-purpose	Total	Landfill	Multi-purpose	Total
NSW	2.4.1.3.1.1	263	101	364	35	19	54
VIC	2.4.1.3.1.2	156	45	201	7	0	7
NT	2.4.1.3.1.3	140	4	144	1	0	1
WA	2.4.1.3.1.4	254	29	283	2	3	5
SA	2.4.1.3.1.5	109	24	133	4	1	5
QLD	2.4.1.3.1.6	226	35	261	30	0	30
TAS	2.4.1.3.1.7	17	2	19	NA	NA	
ACT	2.4.1.3.1.8	1	1	2	1	0	1
Total		1,166	241	1,407	80	23	103

Note: NA (Not available).

[20] It is noted that the data may contain duplicated records for a single site. The data may have also considered non-operational sites.

2.4.1.3.1.1 New South Wales

New South Wales licences were made available by the NSW Environmental Protection Agency (EPA) POEO[21] Public Register[22]. Licences were searched by the fee-based activity for 'waste disposal by application to land', returning all available licences in the State for this activity. It is noted that 157 records were found. The licences do not provide details of the landfill size. A representative example of actual licence conditions is provided below (*emphasis added*):

> *Landfill Gas Oxidation*
>
> O5.14 Except in emergency conditions or short periods of shutdowns the licensee must ***ensure that landfill gas generated*** by the disposal of waste and collected at the premises is ***treated by oxidation to carbon dioxide***.

2.4.1.3.1.2 Victoria

Victoria licences were made available by the VIC EPA Interaction Portal[23]. Reviewed licences indicated that requirements are general and refer to the Best Practice Environmental Management (BPEM) Guidelines. The licences do not provide details of the landfill size. A representative example of actual licence conditions is provided below (*emphasis added*):

> *Landfill Conditions*
>
> LI_L5 You must ***take all practicable measures to prevent emissions of landfill gas from exceeding the action levels*** specified in Table 6.4 of Best Practice Environmental Management, Siting, Design, Operation and Rehabilitation of Landfills (EPA Publication 788.3, released August 2015).

2.4.1.3.1.3 Northern Territory

The only Northern Territory licence that could be retrieved was made available by the NT EPA website[24]. In the licence, the landfill gas requirements are general in nature. There are eight (8) landfills listed in the page. It is understood the licence retrieved is the biggest landfill in the Territory. The licences do not provide details of the landfill size. A representative example of actual licence conditions is provided below (*emphasis added*):

> *Licence Conditions*
>
> Emissions to air
>
> 42 The licensee must ensure that pollution control equipment, ***including landfill gas collection equipment, is installed, operated and maintained*** to minimise contaminants or waste in emissions to air.

---

[21] Protection of the Environment Operations

[22] List of Licenses available at http://www.epa.nsw.gov.au/prpoeo/licences.htm

[23] EPA Interaction Portal, last accessed on 7 August 2017, from https://portal.epa.vic.gov.au/irj/portal/anonymous?NavigationTarget=ROLES://portal_content/epa_content/epa_roles/epa.vic.gov.au.anonrole/epa.vic.gov.au.searchanon&trans_type=Z001

[24] Information retrieved on 14 July 2017 from https://ntepa.nt.gov.au/waste-pollution/approvals-licences/environment-protection-licences

2.4.1.3.1.4 Western Australia

Western Australian licences were made available by WA Department of Water and Environmental Regulation website[25]. The reviewed licences indicated that the requirements are site specific. The publicly available licences are scanned copies, often illegible, incorrectly formatted, cropped and often missing pages. A representative example of actual licence conditions is provided below (*emphasis added*):

> Landfill Conditions
>
> Licence Condition 1.2.9 has been added to the Licence to ensure that collection and combustion of landfill gas occurs within reasonable timeframes to mitigate asphyxiation, explosion and migration potential.
>
> 1.2.9 The Licensee must connect infrastructure detailed in Item 3 ('Aspiration wells'), Column 1 of Table 1.2.1 to active landfill gas management systems *capable of capture and combustion of landfill gas* no later than 90 days following the completion of the construction of those wells.

2.4.1.3.1.5 South Australia

South Australian licences were made available by the SA EPA search authorisations[26]. Licences were searched by the activity for 'waste or recycling depots (solid waste for on-site disposal)', returning all available licences in the State for this activity. The licences do not provide details of the landfill size. A representative example of actual licence conditions is provided below (*emphasis added*):

> *Conditions of Licence*
>
> 3.13 Revised Landfill Environment Management Plan (U - 393)
>
> The Licensee must:
>
> 3.13.2 Ensure the Northern Adelaide Waste Management Authority Landfill Environmental Management Plan includes but not be limited to updating the management of groundwater, leachate, surface water, landfill gas, landfill capping and closure and post closure monitoring.

2.4.1.3.1.6 Queensland

Queensland licences are divided mainly in two, as follows:

- ERA 60 - Waste disposal 1: Operating a facility for disposing of, in a year, the following quantity of waste mentioned in subsection (1)(a)
  a) less than 50,000t
  b) 50,000t to 100,000t
  c) more than 100,000t but not more than 200,000t
  d) more than 200,000t
- ERA 60 - Waste disposal 2: Operating a facility for disposing of, in a year, the following quantity of waste mentioned in subsection (1)(b)
  a) 50t to 2,000t
  b) more than 2,000t but not more than 5,000t
  c) more than 5,000t but not more than 10,000t
  d) more than 10,000t but not more than 20,000t

---

[25] Information retrieved on 14 July 2017 from https://www.der.wa.gov.au/our-work/licences-and-works-approvals/current-licences

[26] Information retrieved on 14 July 2017 from http://www.epa.sa.gov.au/data_and_publications/environmental_authorisations_licences/search-authorisations#/search?location=area&type=A

e) more than 20,000t but not more than 50,000t
f) more than 50,000t but not more than 100,000t
g) more than 100,000t but not more than 200,000t
h) more than 200,000t

Depending on the annual tonnes a landfill is licenced for, the specific landfill gas requirements vary. Below, the smallest landfill site licence (i.e. ERA 60 Waste disposal 1(a) – less than 50,000t) and the biggest (i.e. ERA 60 Waste disposal 2(h) - more than 200,000t) are provided below. It is noted that (from the licences reviewed – refer to Table 9) most of the licences do not have a requirement to capture and combust any landfill gas. Nevertheless, for the bigger landfill sites (i.e. from ERA 60 2 (e) onwards), the requirements to manage landfill gas is present (although not for all the landfills that fall in that category). Some of the requirements are provided below (*emphasis added*) and more detailed information is provided in Appendix H.

Conditions of Licence (ERA 60 Waste disposal 1 (a)

No requirement

Conditions of Licence (ERA 60 Waste disposal 2 (h))

Management of Landfill Gas

(B3) A collection system for landfill gas *must be installed and maintained to efficiently minimise*:

i. any likelihood of any *subsurface migration of landfill gas from the landfill unit*; and
ii. any uncontrolled emission of landfill gas.

(B4) An interim perimeter active landfill gas collection system for all cells must be installed prior to installation of the final gas collection system. This system is to be installed forthwith after the landfill cell is sufficiently elevated to allow adequate drainage of gas lines.

(B5) *Landfill gas collected by the gas collection system must be incinerated* prior to release to the atmosphere or provided as an alternative fuel source or collected and stored in a proper and efficient manner for later use.

(B11) There must be no visible emissions from the landfill gas flare.

(B12) The release of landfill gas from the landfill must not exceed:

i. *25 percent of the lower explosive limit for methane* when measured in landfill facility structures (but excluding landfill facility structures used for landfill gas control and landfill gas recovery system components); and
ii. the lower explosive limit for methane at the landfill facility boundary.

2.4.1.3.1.7 Tasmania

Whilst no licences could be retrieved, interviews with the EPA regulator indicated the following requirements:

Landfill Requirements

OP8 – Landfill gas management

- If waste deposition on The Land, excluding cover material, exceeds 20,000 tonnes per annum in any three consecutive years, landfill gas management infrastructure must be installed progressively as final capping is installed; and
- Following installation of landfill gas management infrastructure *landfill gas must either be collected and reused, or flared*.

2.4.1.3.1.8 Australian Capital Territory

Licence (authorisation) No. 0375 for Remondis Australia Pty Ltd was consulted. The below are the gas management requirements:

Landfill Requirements

27 Gas Management

27.1 The Authorisation holder shall undertake a site-specific landfill gas risk assessment acceptable to the Authority within three (3) months of the approval of this Authorisation.

27.2 The Authorisation holder shall undertake monitoring of landfill gas in accordance with section 6.7.1 landfill gas and Table 6.4 of the 'Best practice environmental management, siting, design, operation and rehabilitation of landfills' (Victorian Environment Protection Authority publication 788) as updated from time to time and record the following information on a monthly basis:

- methane concentration;
- carbon dioxide concentration;
- landfill gas temperature; and
- atmospheric temperature and pressure.

27.3 The Authorisation holder shall provide the Authority with a written report once per calendar month from the grant date of this authorisation detailing the results obtained in undertaking the monitoring as detailed in condition 27.2.

Conclusion 8 Landfill licences vary across States and within States (e.g. depending on the landfill size) and are applicable to individual sites. Some landfill licences do require landfill gas capture and management. Despite the requirement being intended to mitigate potential risks, these requirements result in GHG emissions mitigation. It is noted that because these requirements do not specify the extent of (i.e. how much gas) landfill gas that must be managed (e.g. captured and combusted), these requirements account for the 30% qualitative baseline in the Methodology.

2.5 Whether the additionality requirements of the method present a barrier to projects that would provide genuine and additional abatement.

Summary:

There are barriers to projects that would provide genuine and additional abatement including:

- *the qualitative baseline, particularly in Victoria, and*
- *the non-carbon tax waste percentage calculations, particularly for small landfills.*

2.5.1 Qualitative baseline

As previously highlighted in section 2.2.4, the qualitative baseline is a key element of the Methodology. With this baseline being a flat 30%, it is possible that some projects face a barrier for receiving ACCUs for genuine additional abatement. The baseline tests were designed in 2011 using data available at the time.

2.5.1.1 Victorian quantitative test

As previously highlighted in section 2.2.4.3, Equation 13 and Equation 22 (quantitative) in the Methodology reference regulatory requirements for maximum methane concentration above the surface of the landfill. Applying these to Victorian sites, assuming a maximum 100 parts per million (ppm) of methane concentration above the surface of the landfill, results in a baseline greater than the default 30% (refer to report sections 2.2.4.3.1, 5.2 and Appendix I.) This results in a reduced number of eligible ACCUs.

As detailed in section 2.2.4.3, we understand that this has led to fewer new Victorian landfill gas projects being undertaken, and consequently less abatement occurring. Only one new landfill gas project has been registered in Victoria; all other Victorian projects were registered under GGAS and have been able to transition directly into the CFI/ERF[27]. The one new project that has been accredited in Victoria is yet to create an ACCU. Other states have multiple new (not transitioned from GGAS or Greenhouse Friendly) projects registered and creating ACCUs.

2.5.1.2 NSW Landfill Guide Requirements

From general industry knowledge, smaller New South Wales landfills generally did not capture gas and presumably did not have a specific requirement to do so, before the commencement of the Carbon Farming Initiative. However, the qualitative rule in the Methodology has been assumed to apply throughout New South Wales, setting a 30% baseline.

The guideline[28] suggests landfill gas capture should occur. Nevertheless, the guideline requirements have not been referenced in landfill licences (i.e. the licences do not require gas capture and management or reference the guideline). Rather, licences refer to legislative requirements (e.g. not to cause offsite odour). The strict interpretation of this provision could act as an additionality barrier for some smaller projects where, in practice, there are no particular constraints.

Conclusion 9 The existing baseline arrangements in the Methodology may represent a barrier, particularly for potential projects in Victoria where a lower maximum parts-per-million (ppm) of methane concentration above the surface of the landfill, can result in a baseline greater than the default 30%.

2.5.2 Non-Carbon Tax Calculations

Under the landfill gas Methodology, the non-carbon tax emissions must be taken into account. For large sites, this calculation is a requirement under NGER. For a smaller landfill, which does not have to otherwise perform this analysis, the requirement of these calculations may present a barrier. A landfill may decide not to register a project if they believe the calculation requirements and the risks associated with reporting information subsequently deemed incorrect are too high.

[27] ERF project register http://www.cleanenergyregulator.gov.au/ERF/project-and-contracts-registers/project-register accessed 31 August 2017.
[28] Environmental guidelines, solid waste landfills, Second edition, 2016. Environment Protection Authority. Available at www.epa.nsw.gov.au.

Example:

For a Victorian landfill opened in 2000 and which accepted 100,000 tonnes of default waste, for example, the % non-carbon tax emissions would be as tabulated below.

Table 10: Non-Carbon Tax Emissions Example

Year	Total emissions ($ktCO_2$-e)	Non-carbon tax emissions ($ktCO_2$-e)	% Non-carbon tax emissions
2015	44.7	36.7	82.0%
2016	46.7	39.1	83.6%
2017	48.6	41.3	85.0%
2018	50.4	43.6	86.3%

Undertaking this calculation involves using the Clean Energy Regulator's (CER) solid waste calculator to estimate emissions from each year of deposited waste within a claim, and then determining the percentage of emissions from waste not deposited during the carbon tax years[29].

Where landfills report under NGER, this calculation is not overly difficult, as the required information is already collected and collated, and such landfills are familiar with the solid waste calculator. For smaller sites that do not report under NGER, however, the data requirements may be onerous. The project participant must report annual tonnages, and the proportional split across waste type, since the landfill opened. The project proponent does not generally have access to this historical data, and it is often incomplete, based on low quality estimates, and difficult to compile to a standard acceptable to auditors.

Conclusion 10 The non-carbon tax emissions calculation requirement may present a barrier, particularly for small landfills which do not need to carry out this calculation for NGER reporting.

2.6 If not all projects under the method are likely to be additional, whether there is a subset or class of activities/project types which might remain additional.

Summary:

All landfill gas projects accredited are currently additional. An extension of the crediting period will enable emissions from these projects to continue to be optimally abated. Data available since the baseline calculations were designed in 2011 could be used to update the baseline calculation for any extended crediting period.

Based on the assessment performed to prepare this report, it appears that all currently accredited projects are additional. The additionality tests (i.e., newness, regulatory and government programs) are effective in accrediting projects that will create additional abatement.

[29] Carbon tax years spanned 1 July 2012 – 30 June 2014.

2.6.1 Baseline determination

The major issue for landfill gas projects regarding additionality is the determination of the baseline, and whether it is appropriate. As stated above, the authors believe that, across the industry, the current baselines are appropriate, but that going forward the determination of the baseline should be revisited. The parts per million (ppm) methane threshold concentration levels shown in Table 8 could represent baselines for the relevant States and Territories. Translating these requirements into a gas capture rate requirements can be performed using site-specific information. Information such as gas generation rates, landfill depth, and landfill cover types by area are needed, which are currently already required under the Methodology.

Legislative gas capture rates required for compliance could be investigated through performing a detailed assessment using:

- collated records of landfill gas compliance monitoring,
- reports or more general assessments of compliance, potentially done by a third party,
- knowledge of exceptions – landfills that have been non-compliant, and
- an informed opinion on general levels of compliance in their jurisdiction.

Each of these has parallels with Schedule 1 of the Methodology, and could better inform decisions on qualitative baselines.

<u>Conclusion 11</u> The baseline determination is the major reflection of additionality for a landfill gas project. The current default baseline of 30% was evaluated in 2011. Data from projects in operation since then could be used to develop new baselines, particularly to determine additionality levels upon entering an extension period.

2.6.2 Continual capital investment for landfill gas projects

Landfill gas projects typically require continuous operating expenditure (i.e., landfill gas projects do not involve a once-off capital investment project). This continuous investment is required as landfill cells are developed on an ongoing basis throughout the landfill life. Once a cell is filled, a new cell is created and new waste is deposited. In large cells, additional infrastructure may be needed as the cell is filled. For a landfill gas project to continue to create abatement, the project needs to capture abatement from the new waste deposited in the landfill. This requires ongoing investment in new gas capture infrastructure (refer to section 6.3 for more information).

Gas collection infrastructure also requires ongoing maintenance, including the replacement of blocked wells. To incentivise abatement from new waste, the landfill gas project may need to create carbon credits or have income from the electricity generation. If these financial incentives are not available, landfill gas collection may decline to that needed to meet the minimum regulatory requirements (if any).

<u>Conclusion 12</u> The continuous cell development process in landfills, means that ongoing investment is required if gas capture and management is to be maintained. If financial incentives such as from the creation of ACCUs and electricity generation (as applicable) are not available, gas collection and management may decline.

3 Assessment of whether the emissions removal or reduction, as the case may be, are measurable and capable of being verified

Summary:

The calculations set out in the landfill gas Methodology allow the abatement delivered by the project to be quantified. Equations utilised vary depending on the project type, therefore the use of calculations is tailored to different projects. The Methodology clearly sets out the equations and how these should be applied to quantify the volume of landfill gas sent to destruction devices. The volume of landfill gas sent to a destruction device is measured by scientifically robust devices. The process of calculating the volume of methane destroyed is also robust.

There are some differences between the 2012 and 2015 Methodologies. This section distinguishes between the two Methodologies, where relevant. The 2015 Methodology is used as the basis for discussion with any differences with the 2012 Methodology either acknowledged in brackets or described in the subsequent sub-section.

3.1 Whether abatement delivered by eligible projects can be quantified using the calculation approaches set out in the method

Part 4 of the 2015 Methodology (Part 3 of the 2012 Methodology) and explanatory statement describe in detail how to calculate the net abatement that has occurred in an eligible project. There are many calculations that need to be conducted to determine how much abatement a project has achieved in each reporting period. In general, these calculations allow projects to quantify abatement using a consistent and scientifically robust approach that is verifiable. There are however some considerations from a measurement and verification perspective that are described below.

3.1.1 2015 Methodology considerations

Figure 8 (baseline abatement) and Figure 9 (project abatement) provide an overview of these equations for the 2015 Methodology. For the 2015 Methodology, the net abatement is calculated as the project abatement minus the baseline abatement. ACCUs are granted only for the abatement achieved in the project that goes beyond what would have been achieved without the project (i.e., the baseline abatement).

3.1.1.1 Baseline abatement

The baseline abatement is the methane combusted during the project and generated by non-carbon tax waste, multiplied by the proportion of methane that would have been combusted without the project. The determination of this proportion depends on the type of project. Equations 12 to 19 of the Methodology (Part 4 Division 4) are used to determine the baseline abatement. The main steps include determining the regulatory proportion, default baseline proportion and baseline proportion.

The baseline reduces the number of ACCUs the project receives, based on the volume of gas that would have had to be captured for regulatory purposes had the project not been accredited under the ERF. The application of the baseline effectively forms part of the *regulatory additionality test*. It determines how many ACCUs can be created based on how much gas would need to be captured to meet regulatory requirements. It is noted that it is not possible to capture all the gas from a landfill (refer to section 6.2). Regulatory requirements for gas capture vary greatly between jurisdictions and between sites, as described in section 2.1.3.

The regulatory proportion can be determined by following the guidance provided by the Methodology and the CER. The default baseline proportion represents qualitative regulatory requirements and is either 30 per cent or zero per cent (or a different percentage for transitioning projects). The baseline abatement is measurable and verifiable as the project proponent can provide the auditor with the relevant regulatory requirements applicable to the landfill. Evidence required for verification can include state or territory legislation, regulatory guidelines for the landfill, landfill licenses, etc. From a verification perspective, there is a potential detection risk[30], as it may not be possible to review all of the relevant regulatory requirements; however, it is the responsibility of the project proponent to provide the supporting information to justify the baseline proportion. Refer to section 4.2 for more information.

Conclusion 13 The baseline abatement can be quantified using the calculation approaches set out in equations 12 to 19 of the 2015 Methodology. To assess this the equations in the Methodology (summarised in Figure 8) have been reviewed and allow quantification. The Methodology, explanatory statement, and guidance are sufficient for this to be calculated and verified.

3.1.1.2 Project abatement

The project abatement is calculated as the amount of methane (generated by non-carbon tax waste) combusted by the project minus the amount that would have been oxidised near the surface of the landfill had it not been collected during the project.

Equations 2 to 11 of the Methodology (Part 4 Division 3) are involved in calculations to determine project abatement. Figure 9 summarises these equations with further assessment of each equation and parameter included in Table 11. Each equation has been assessed as to whether it is quantifiable and verifiable. By reviewing each equation, it can be concluded that all parameters and equations can be quantified if the calculations and monitoring requirements are adhered to. For verification, it is important that the supporting data (including source, i.e., raw data) from all monitoring and measurement devices are retained.

[30] Detection risk is the audit risk that it may not be detected in the audit, i.e. it is possible that not all of the regulatory requirements are known by the auditor.

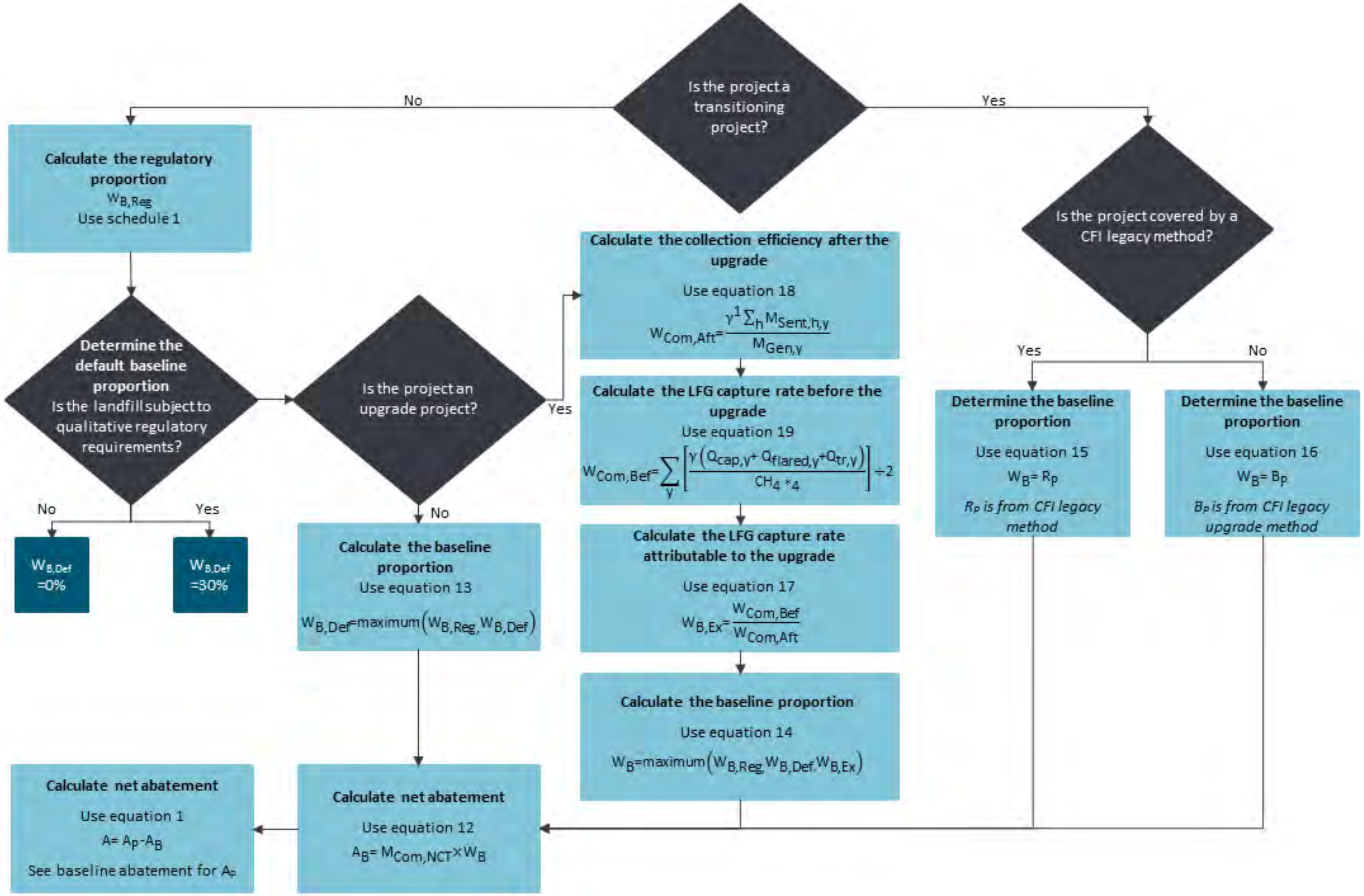

Figure 8: Equation flowchart – baseline abatement (CER, 2015)[31]

[31] Clean Energy Regulator (2015), "Participating in the Emissions Reduction Fund: A guide to the landfill gas method 2015", retrieved on 20 August 2017 from: http://www.environment.gov.au/climate-change/emissions-reduction-fund/methods/landfill-gas

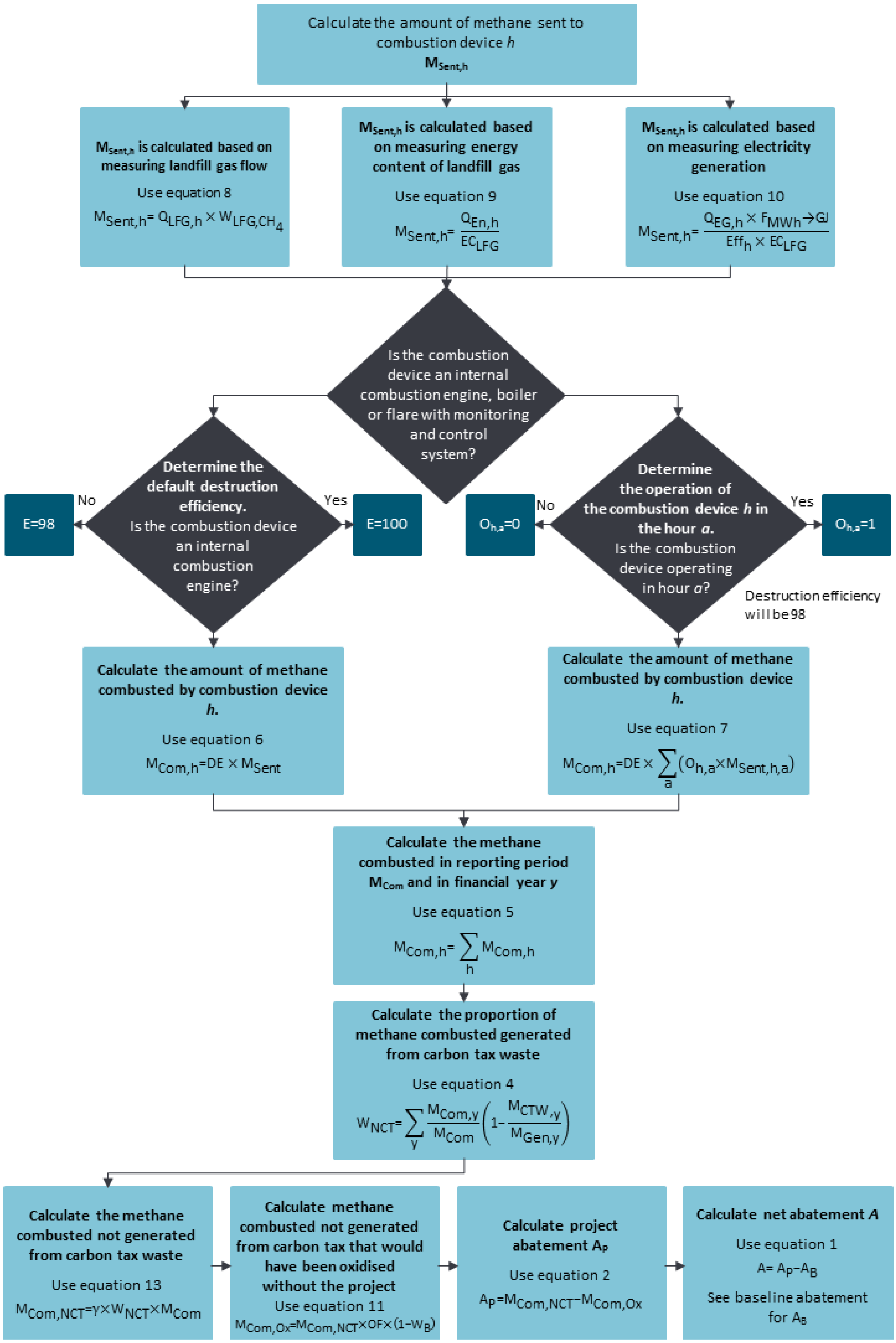

Figure 9: Equation flowchart – project abatement (CER, 2015)

Table 11: Assessment of quantification and verification of requirements (2015 Methodology)

Part	Equation number/ source (if applicable)	Parameter (if applicable)	Parameter description (if applicable)	Equation (if applicable)	Quantifiable?	Verifiable?
18	1	A	The carbon dioxide equivalent net abatement amount for the reporting period, in tCO_2-e	$A = A_P - A_B$	Yes - A_P is worked out using equation 2 and A_B is worked out using equation 12	Yes - if equations 2 and 12 are worked out correctly with the required supporting data from those equations.
20	2	Ap	The project abatement for the reporting period, in tCO_2-e	$A_P = M_{Com,NCT} - M_{Com,Ox}$	Yes - $M_{com,NCT}$ is worked out using equation 3 and $M_{com,Ox}$ is worked out using equation 11	Yes - if equations 3 and 11 are worked out correctly with the required supporting data from those equations.
	$M_{Com,NCT}$	$M_{Com,NCT}$	The methane combusted during the reporting period that was not generated from carbon tax waste, in tCO_2-e, worked out using equation 3	See equation 3		
	$M_{Com,Ox}$	$M_{Com,Ox}$	The methane combusted during the reporting period that was not generated from carbon tax waste and that, without the project, would have been oxidised in near surface conditions of landfill, in tCO_2-e, worked out using equation 11	See equation 11		
21	3	$M_{Com,NCT}$	See description above in equation 2	$M_{Com,NCT} = \gamma \times W_{NCT} \times M_{Com}$	Yes - γ is a standard unit conversion as described by NGER Measurement determination, W_{NCT} is worked out using equation 4, and M_{com} is worked out using equation 5	Yes - if equations 4 and 5 are worked out correctly and the NGER conversion factor applied in accordance with the Measurement Determination. Supporting data from equations 4 and 5 is required for verification.
		γ	Means the factor to convert cubic metres of methane at standard conditions to tCO_2-e worked out using subsection 5.4(1) of the NGER (Measurement) Determination			
		W_{NCT}	The proportion of the methane combusted during the reporting period that was not generated from carbon tax waste worked out using equation 4	See equation 4		
		M_{Com}	The methane that was combusted during the reporting period, in cubic metres, worked out using equation 5	See equation 5		

Part	Equation number/ source (if applicable)	Parameter (if applicable)	Parameter description (if applicable)	Equation (if applicable)	Quantifiable?	Verifiable?
22	4	W_{NCT}	See description above in equation 3	$W_{NCT} = \sum_{y} \frac{M_{Com,y}}{M_{Com}} \left(1 - \frac{M_{CTW,y}}{M_{Gen,y}}\right)$	Yes - W_{NCT} is quantifiable, however there are complexities associated with calculating this due to some potential issues with historical source data and landfill waste data quality (section 2.5.2). Quantification is possible through the use of the CER's ERF landfill gas calculator and the NGER solid waste calculator.	Yes - W_{NCT} is verifiable but it is likely there could be challenges with the source data quality, i.e. historical records of waste composition received at the landfill over past years may be limited or inaccurate. In some cases, it can be difficult to verify as there may not be sufficient and appropriate evidence to provide reasonable assurance.
		$M_{Com,y}$	The methane combusted in financial year y, in cubic metres, worked out using equation 5 as if a reporting period were a financial year	See equation 5		
		$M_{CTW,y}$	The methane generated by the landfill from carbon tax waste in financial year y in tCO_2-e calculated in accordance with subsection (2)			
		$M_{Gen,y}$	The methane generated by the landfill in financial year y, in tCO_2-e, calculated in accordance with subsection (3)			
23	5	M_{Com}	The methane combusted during the reporting period, in cubic metres.	$M_{Com} = \sum_{h} M_{Com,h}$	Yes - if the methane sent to combustion device h can be worked out using equation 8, 9 or 10. The operational hours must also be known for 'other combustion devices'.	Yes - if equations 8, 9 or 10 are worked out correctly with the required supporting data, e.g. gas flow meter data and methane concentration. The operational hours must also be known for 'other combustion devices'.
	6	$M_{com,h}$	If combustion device h is a boiler, a flare with monitoring and control system or an internal combustion engine, the methane combusted during the reporting period by the device, in cubic metres	$M_{Com,h} = DE \times M_{sent,h}$	Yes - if the methane sent to combustion device h can be worked out using equation 8, 9 or 10.	Yes - if equations 8, 9 or 10 are worked out correctly with the required supporting data from those equations. Of crucial importance is the measurement of methane sent to combustion device h.
		DE	The default methane destruction efficiency for a combustion device, which for an internal combustion engine is 1 and for any other combustion device is 0.98			

Part	Equation number/ source (if applicable)	Parameter (if applicable)	Parameter description (if applicable)	Equation (if applicable)	Quantifiable?	Verifiable?
23 (cont)	6 (cont)	$M_{Sent,h}$	The methane sent to combustion device h during the reporting period, in cubic metres, worked out using equation 8, 9 or 10.	See equation 8, 9 or 10		
	7	$M_{com,h}$	If combustion device h is not a boiler, a flare with monitoring and control system or an internal combustion engine, the methane combusted during the reporting period by the device, in cubic metres	$M_{com,h} = DE \times \sum_a (O_{h,a} \times M_{Sent,h,a})$	Yes - if the methane sent to combustion device h can be worked out using equation 8, 9 or 10. The operational hours must also be known.	Yes - if equations 8, 9 or 10 are worked out correctly with the required supporting data from those equations. The operational hours must also be known. Of crucial importance is the measurement of methane sent to combustion device h.
		$O_{h,a}$	The operation of combustion device h in hour a, which is either 0 or 1			
		$M_{Sent,h,a}$	The methane sent to combustion device h in hour a, in cubic metres, worked out using equation 8 or 9			
24	8	$M_{Sent,h}$	*Option 1—using landfill gas sent to combustion device*	$M_{Sent,h} = Q_{LFG,h} \times W_{LFG,CH4}$	Yes - if $Q_{LFG,h}$ and $W_{LFG,CH4}$ are measured in accordance with monitoring requirements and/or NGER measurement determination	Yes - if $Q_{LFG,h}$ and $W_{LFG,CH4}$ are correctly measured with the required supporting data, i.e. gas flow measurement data from the monitoring and control system.
		$Q_{LFG,h}$	The landfill gas sent to the combustion device h during the period, in cubic metres			
		$W_{LFG,CH4}$	The proportion of the volume of the landfill gas that is methane			
	9	$M_{Sent,h}$	*Option 2—using energy content of landfill gas sent to combustion device*	$M_{Sent,h} = \frac{Q_{En,h}}{EC_{LFG}}$	Yes - if $Q_{En,h}$ and EC_{LFG} are measured in accordance with monitoring requirements and/or NGER measurement determination	Yes - if $Q_{En,h}$ and EC_{LFG} are correctly measured with the required supporting data, i.e. energy measurement data from the monitoring and control system.
		$Q_{En,h}$	The energy content of the landfill gas sent to the combustion device h during the period, in gigajoules			
		EC_{LFG}	The energy content factor for landfill gas that is collected for combustion (methane only), in gigajoules per cubic metre			

Part	Equation number/ source (if applicable)	Parameter (if applicable)	Parameter description (if applicable)	Equation (if applicable)	Quantifiable?	Verifiable?
24 (cont)	10	$M_{Sent,h}$	*Option 3—using electricity produced by internal combustion engine*	$M_{Sent,h} = \frac{Q_{EG,h} \times F_{MWh \to GJ}}{Eff_h \times EC_{LFG}}$	Yes - if $Q_{EG,h}$ Eff_h and EC_{LFG} are measured in accordance with monitoring requirements and/or NGER measurement determination	Yes - if $Q_{EG,h}$ Eff_h and EC_{LFG} are correctly measured with the required supporting data, i.e. electricity measurement data from the monitoring and control system.
		$Q_{EG,h}$	The electricity (supplied to the grid or used on-site) produced by internal combustion engine h during the period, in megawatt hours			
		$F_{MWh \to GJ}$	The factor to convert megawatt hours to gigajoules, which is 3.6			
		Eff_h	The factor for the electrical efficiency of internal combustion engine h			
		EC_{LFG}	The energy content factor for landfill gas that is captured for combustion (methane only), in gigajoules per cubic metre			
25	11	$M_{Com,Ox}$	The methane combusted during the reporting period that was not generated from carbon tax waste and that, without the project, would have been oxidised in near surface conditions of landfill, in tCO_2-e	$M_{Com,Ox} = M_{com,NCT}$ x OF x (1-W_B)	Yes - $M_{com,NCT}$ is worked out using equation 3, OF is a default parameter and Wb relates to the baseline abatement worked out using equations 13 to 16	Yes - if equation 3 is correctly measured with the required supporting data, and the baseline abatement is determined correctly
		$M_{Com,NCT}$	The methane combusted during the reporting period that was not generated from carbon tax waste, in tCO_2-e	See equation 3		
		OF	Means the oxidation factor for near surface methane in landfill set out in the definition of OF in subsection 5.4(1) of the NGER (Measurement) Determination			
		Wb	The proportion of the methane combusted in the reporting period that would have been combusted without the project worked out using whichever of equations 13 to 16 applies			

Part	Equation number/ source (if applicable)	Parameter (if applicable)	Parameter description (if applicable)	Equation (if applicable)	Quantifiable?	Verifiable?
27	12	Ab	The baseline abatement for the reporting period, in tonnes CO_2-e	$A_B = M_{Com,NCT}$ xW_B	Yes - $M_{com,NCT}$ is worked out using equation 3 and Wb is worked out using whichever of equations 13 to 16 applies	Yes - if equations 3 and whichever of equations 13 to 16 are worked out correctly with the required supporting data obtained from equations 3 and 16.

There are some aspects of the calculation methods that can be complex and have the potential to make verification more difficult - for example:

- Calculation of the proportion of methane combusted that was generated from non-carbon tax waste (refer to section 2.5.2 for more information);
- Historical waste composition and volume data records, as required in the landfill gas model. Auditable records going back 20 years or more are often difficult to obtain or verify;
- Non-monitored periods can have uncertainties, depending on which instruments or meters were the source of malfunctions (i.e. not working correctly or still operating). It may be possible to estimate a parameter using alternative data or information, for example:
    - electricity generation could be used to estimate gas flow if the engine efficiency is known. So, if a gas flow meter is broken, a non-monitored period may still be verifiable. However, if the gas is flared but the composition or flow rate is not known, verification is more difficult.
- Operation of combustion device *h* during hour *a* requires at least 40 minutes of operation. However, data loggers may work on 10, 15 or 20 minutes. Consequently, incorrect or failed measurements could be difficult to verify (refer to section 3.2.1.1).

Nonetheless, as various data is required to be collected in order to perform the calculations required in the Methodology, this data provides the basis for the quantification of abatement and gives a fully verifiable method.

Table 11 describes the equations and highlights the key parameters that need to be accurately monitored so the abatement can be quantified and verified. Further assessment of the monitoring, measurement and data collection is provided in response to the subsequent sections of the report.

<u>Conclusion 14</u> By conducting a detailed review of all of the equations and parameters in the 2015 Methodology (summarised in Table 11), it is clear that the abatement delivered by eligible projects can be quantified using the calculation approaches set out in the Methodology. Net abatement in the Methodology is fully verifiable if the equations have been worked out correctly and the supporting data for each parameter is available.

3.1.2 2012 Methodology considerations

The 2012 Methodology essentially follows a very similar calculation approach as the 2015 Methodology. There are however some minor differences in the system boundary (see section 4.1.4) and therefore some additional parameters are required for the 2012 Methodology. In addition, the names and symbols used for the measured/monitored parameters have some differences (see section 3.2 and section 4.1.3). As with the 2015 Methodology, the calculations defined in the projects allow projects to quantify abatement using a consistent and scientifically robust approach that is verifiable. Table 12 assesses the equations and highlights the key parameters that need to be accurately monitored so the abatement can be quantified and verified.

Table 12: Assessment of quantification and verification of requirements (2012 Methodology)

Equation number/source (if applicable)	Parameter (if applicable)	Parameter description (if applicable)	Equation (if applicable)	Quantifiable?	Verifiable?
1	A	The net abatement amount for an offsets project to which this Methodology Determination applies for a reporting period, in tCO_2-e	$A = (A_p - Y_p)$	Yes - once A_p and Y_p are calculated	Yes - this requires A_p and Y_p to be calculated
2	A_p	Quantity of emissions avoided as a consequence of the project, in tCO_2-e	$A_p = \left[\left(\gamma \sum_{h=1}^{n} Q_{com,h}\right) - A_{reg}\right] \times (1 - OF) - E_{com}$	Yes - if data available for $Q_{com,h}$	Yes - if data available for $Q_{com,h}$
2(a)	A_p	Quantity of emissions avoided as a consequence of the project, in tCO_2-e	$A_p = \left[\left(\gamma \sum_{h=1}^{n} Q_{com,h}\right) + A_{com,ice} - A_{reg}\right] \times (1 - OF) - E_{com}$	Yes - if data available for $Q_{com,h}$	Yes - if data available for $Q_{com,h}$
3 (flares)	$\sum_{h=1}^{n} Q_{com,h}$	Volume of methane generated by legacy waste destroyed by combustion device h, in cubic metres	$Q_{com,h} = Q_{sent,h} \times DE_h \times L_p$	Yes - if data available for $Q_{sent,h}$	Yes - if data available for $Q_{sent,h}$
3 (internal combustion engine)		Volume of methane generated by legacy waste destroyed by combustion device h, in cubic metres	$Q_{com,h} = Q_{sent,h} \times DE_h \times L_p$	Yes - if data available for $Q_{sent,h}$	Yes - if data available for $Q_{sent,h}$
4a	$Q_{sent,h}$	Volume of methane sent to combustion device h, in cubic metres	$Q_{sent,h} = Q_{lfg,h} \times W_{CH_4}$	Yes - if data available for $Q_{lfg,h}$	Yes - if data available for $Q_{lfg,h}$
4b	$Q_{sent,h}$	Volume of methane sent to combustion device h, in cubic metres	$Q_{sent,h} = E_{lfg} \times \frac{1}{EC_{biogas}}$	Yes - if data available for E_{lfg}	Yes - if data available for E_{lfg}
5	E_{com}	Quantity of methane emissions and nitrous oxide emissions released from all combustion devices, in tCO_2-e	$E_{com} = E_{rel,CH_4} + E_{N_2O}$	Yes - this uses NGER emission factors	Yes - if volume of methane destroyed is known
6	$E_{rel,CH4}$	Quantity of methane emissions from legacy waste released from all combustion devices, in tCO_2-e	$E_{rel,CH_4} = \gamma \sum_{h=1}^{n} Q_{rel,h} \times OF$	Yes - this requires $Q_{rel,h}$ to be calculated	Yes - if data available for $Q_{rel,h}$

Equation number/source (if applicable)	Parameter (if applicable)	Parameter description (if applicable)	Equation (if applicable)	Quantifiable?	Verifiable?
6(a)	$E_{rel,CH4}$	Quantity of methane emissions from legacy waste released from all combustion devices, in tCO_2-e	$E_{rel,CH_4} = \left[\left(\gamma \sum_{h=1}^{n} Q_{rel,h}\right) + \left(\left(\sum_{h=1}^{n} QE_h \times (1 - DE_h)\right) \times CH_4 factor \times GWP_{CH_4} \times L_p\right)\right] \times OF$	Yes - this requires $Q_{rel,h}$ and QE_h to be calculated	Yes - if $Q_{rel,h}$ and QE_h calculated correctly
7	$\sum_{h=1}^{n} Q_{rel,h}$	Volume of methane generated from legacy waste not destroyed by combustion device h, in cubic metres	$Q_{rel,h} = Q_{sent,h} \times L_p - Q_{com,h}$	Yes - if data available for $Q_{sent,h}$ and $Q_{com,h}$	Yes - if data available for $Q_{sent,h}$ and $Q_{com,h}$
8	E_{N_2O}	Quantity of nitrous oxide emissions released from legacy waste as a result of methane destruction processes from all combustion devices, in tCO_2-e	$E_{N_2O} = \sum_{h=1}^{n} Q_{sent,h} \times EC_{biogas} \times \frac{EF_{N_2O}}{1,000} \times L_p$	Yes - N_2O emissions legacy waste fraction	Yes - N_2O emissions legacy waste fraction
8(a)	E_{N_2O}	Quantity of nitrous oxide emissions released from legacy waste as a result of methane destruction processes from all combustion devices, in tCO_2-e	$E_{N_2O} = \left(\left(\sum_{h=1}^{n} Q_{sent,h} \times EC_{biogas}\right) + \sum_{h=1}^{n} QE_h\right) \times \frac{EF_{N_2O}}{1,000} \times L_p$	Yes - as above using energy content	Yes - as above using energy content
9	$A_{com,ice}$	Quantity of methane generated by legacy waste destroyed as a consequence of combustion in an internal combustion engine, in tCO_2-e	$A_{com,ice} = \left(\sum_{h=1}^{n} Q_{E_h} \times DE_h\right) \times CH_4\ factor \times GWP_{CH_4} \times L_p$	Yes - this just requires the other parameters	Yes - the parameters need to be reviewed
10	QE	Energy content of the methane sent to the internal combustion engine h, in gigajoules (GJ)	$QE_h = \frac{Ep_h \times E_{GJ}}{Eff}$	Yes - this just requires the other parameters	Yes - the parameters need to be reviewed
11	L_p	The proportion of methane generated from legacy waste	$L_p = \frac{M_{lw}}{M_{lw} + M_{plw}}$	Yes - although legacy waste is reliant on historical landfill data quality	Yes - however historical landfill data can be difficult to verify

Equation number/source (if applicable)	Parameter (if applicable)	Parameter description (if applicable)	Equation (if applicable)	Quantifiable?	Verifiable?
12(a)	A_{reg}	The quantity of methane destroyed under baseline conditions, due to regulatory requirements in tCO_2-e	$A_{reg} = \left(\gamma \sum_{h=1}^{n} Q_{com,h} + A_{com,ice}\right) \times R_p$	Yes - $Q_{com,h}$ and $A_{com,ice}$ require the quantity of methane destroyed to be measured	Yes - if supporting data is available for $Q_{com,h}$ and $A_{com,ice}$
13	Y_p	Emissions from fuel and grid-delivered electricity used to operate the landfill gas extraction system to capture and destroy methane generated from legacy waste as a result of the project, in tCO_2-e	$Y_p = Y_t - Y_{reg}$	Yes - see below	Yes - see below
14	Y_t	Total emissions from fuel and grid-delivered electricity used to operate the landfill gas extraction system, in tCO_2-e	$Y_t = (E_f + E_{elec}) \times L_p$	Yes - see below	Yes - see below
15	Y_{reg}	The emissions from fuel and grid-delivered electricity used to operate the landfill gas extraction system to meet regulatory requirements, in tCO_2-e	$Y_{reg} = Y_t \times R_p$	Yes - if Y_t has been calculated	Yes - if Y_t and R_p have supporting data
16	E_f	Total emissions from fuel used (including supplemental natural gas) to operate the landfill gas extraction system, in tonnes of CO_2-e	$E_f = \sum_{i=1}^{n}\sum_{j=1}^{N} E_{ij}$	Yes	Yes - the quantity of fuel can be agreed to invoices/measurement
17	$\sum_{i=1}^{n}\sum_{j=1}^{N} E_{ij}$	Emissions from fuel type (i) of greenhouse gas (j) in tonnes of CO_2-e	$E_{ij} = \frac{Q_i \times EC_i \times EF_{ijoxec}}{1{,}000}$	Yes - this uses NGER emission factors	Yes - the quantity of fuel can be agreed to invoices/measurement
18	E_{elec}	Total emissions from consumption of purchased electricity used to operate the landfill gas extraction system, in tonnes of CO_2-e	$E_{elec} = Q_{elec} \times \frac{EF}{1{,}000}$	Yes - this uses NGER emission factors	Yes - if quantity of electricity can be agreed to meter data

Equation number/source (if applicable)	Parameter (if applicable)	Parameter description (if applicable)	Equation (if applicable)	Quantifiable?	Verifiable?
Measured (section 10)	$Q_{lfg,h}$	Volume of landfill gas sent to combustion device h, in cubic metres	NA	Yes	Yes
Section 10: measured or default (0.5)	$W_{CH4,h}$	The average methane fraction of the landfill gas, calculated using either a default value of 0.5, or measured	NA	Yes	Yes
Measured	$E_{lfg,h}$	The value, calculated by a flow computer, of the energy content of methane in the landfill gas, in gigajoules (GJ)	NA	Yes	Yes
NGER Determination Section 5.4 (1)	EC_{biogas}	The energy content factor for landfill biogas that is captured for combustion as stated in Schedule 1, Part 2 of the *NGER Measurement Determination*	NA	Yes	Yes
NGER Determination Section 5.4 (1)	OF	Oxidation factor for near surface methane in a landfill as stated in Part 5.2 of the *NGER Measurement Determination*	NA	Yes	Yes
Estimate using Regulatory Baseline Guidelines. Defaults: GGAS = 0.24; GF = 0	R_P	The proportion of methane that is required to be captured or destroyed to meet regulatory requirements	NA	Yes	Yes
NGER Solid waste calculator; NGER Determination Part 5.2	M_{lw}	The quantity of methane generated by legacy waste during that part of the reporting period that is after 1 July 2012, in tCO_2-e, calculated using a method specified in Divisions 5.2.2 to 5.2.4 of the *NGER Measurement Determination*	NA	Yes	Yes

Equation number/source (if applicable)	Parameter (if applicable)	Parameter description (if applicable)	Equation (if applicable)	Quantifiable?	Verifiable?
NGER Solid waste calculator; NGER Determination Part 5.2	M_{plw}	The quantity of methane generated by non-legacy waste during that part of the reporting period that is after 1 July 2012, in tCO_2-e, calculated using a method specified in Divisions 5.2.2 to 5.2.4 of the *NGER Measurement Determination*	NA	Yes	Yes
Section 10: measured or default (0.98)	DE_h	Methane destruction efficiency for combustion device h, expressed as a fraction. If the combustion device is an open flare, a default value of 0.98 must be used. Otherwise, either a default value of 0.98 may be used or the methane destruction efficiency of the device can be determined in accordance with section 3.14. If the device is a flare and the flare is not operational, DE_h is zero	NA	Yes	Yes

Conclusion 15 Abatement delivered by eligible projects can be quantified using the calculation approaches set out in the Methodology. This is dependent on the project proponent collecting and appropriately applying the required data. This conclusion is supported by reviewing all the equations and parameters required in the Methodology. As such, the following is confirmed:

- The calculation approaches are straightforward and mathematically robust.
- The net abatement calculations are an accurate representation of reality.
- The Methodology focuses on direct measurement of the key parameters that determine the ACCUs (i.e. the quantity of methane sent to (and destroyed by) the combustion device).
- The 2012 and 2015 Methodologies will yield approximately the same output if the same options (e.g. selecting the default, not measurement data) are selected.
- However, the two Methodologies differ in the circumstances in which different options may be selected and have slightly different system boundaries and parameter requirements.
- Nonetheless if the project proponent follows the equations outlined in the Methodology the net abatement can be accurately calculated.
- The calculated abatement is fully verifiable if the project proponent has followed the requirements for monitoring, measurement and data collection (as assessed in section 3.2)

3.2 Whether requirements in the method for monitoring, measurement and data collection: (i) are appropriate and scientifically/technically valid; (ii) are adequately specified; and (iii) use references to external sources in an accurate and appropriate way.

There are considerable differences between the 2012 and 2015 Methodology in relation to the monitoring, measurement and data collection. Each Methodology has been addressed in a separate section.

3.2.1 2015 Methodology considerations

3.2.1.1 Monitoring and Measurement

The 2015 Methodology (Part 5 Division 2) lists the five parameters used in calculating net abatement amounts that require monitoring. It is noted that not all of these parameters will necessarily apply to a project.

Monitoring requirements are listed in Section 33 of the Methodology (refer to Table 13). The requirements include the process for monitoring and the standard to which it must adhere. A requirement is that measurement procedures are in accordance with relevant NGER (Measurement) Determination specifications which is appropriate and scientifically and technically valid. It is noted that the NGER (Measurement) Determination is based on relevant standards such as the *National Measurement Act 1960*.

If there are no relevant NGER specifications, then a monitored parameter must meet appropriate measuring requirements. In most cases this is specified by the measuring equipment manufacturer technical specification.

The Methodology requires that any equipment or device used to monitor a parameter must be calibrated by an accredited third-party technician at intervals, and using methods, that are in accordance with the manufacturer's specifications. This requirement provides a rigorous scientific approach in theory, and in practice for concentration measurement (typically a gas chromatograph). Nevertheless, it is less usable in practice for flow, temperature and pressure instruments. This is because manufacturers for these instruments may not specify a calibration frequency. The instruments will be calibrated when they leave their factory, however, the manufacturers usually do not provide guidance on calibration frequency for certain applications such as landfill gas measurement installations. Landfill gas can be moist, contain dirt particles and microbiological content.

Table 13 shows that the monitoring and measurement requirements are adequately specified, and section 33 uses references to external sources in an accurate and appropriate way.

Table 13: Requirements to monitor certain parameters (2015 Methodology)

No	Parameter	Description	Unit	Measurement procedure (including frequency as required)	Determination of parameter from measurements
1	$Q_{En,h}$	Energy content of the landfill gas sent to combustion device h	GJ	Estimated under Division 2.3.6 of the NGER (Measurement) Determination or section 6.5 of that Determination using measurement criteria AAA.	Cumulative value for reporting period
2	$O_{h,a}$	Operation of combustion device h during hour a	1 or 0	If the combustion device is a flare, operation is determined for each minute using temperature measurement.	For the purpose of calculating $M_{com,h}$ in equation 7 (above), the value of $O_{h,a}$ determined for an hour based on the operation of the combustion device must be paired to the cumulative value of $M_{sent,h}$ for the same hour
				If temperature is measured at 500 degrees Celsius or higher for 40 minutes or more in an hour, then $O_{h,a}$ = 1. Otherwise $O_{h,a}$ = 0.	
				For all other combustion devices, operation for each minute is to be determined in accordance with manufacturer's specifications.	
				If the device operates according to manufacturer's specifications for the entire hour then $O_{h,a}$ = 1. Otherwise $O_{h,a}$ = 0.	
				All measuring equipment must be used in accordance with appropriate measuring requirements	
3	$Q_{LFG,h}$	Landfill gas sent to combustion device h	Cubic metres	Estimated under Division 2.3.6 of the NGER (Measurement) Determination using measurement criteria AAA.	For equation 7, cumulative values for a time interval not greater than 1 hour must be paired to measurements of $W_{LFG,CH4}$ for the time interval.
				Frequency—continuously	Otherwise, the measurements must be paired to measurements of $W_{LFG,CH4}$ for the same measurement interval

No	Parameter	Description	Unit	Measurement procedure (including frequency as required)	Determination of parameter from measurements
4	$Q_{EG,h}$	Electricity (supplied to the grid or used on-site) generated by internal combustion engine h	MWh	Estimated under Part 6.1 of the NGER (Measurement) Determination.	Cumulative value for the reporting period
				Measure only the electricity produced from the combustion of landfill gas (not from the combustion of other fuel types)	
5	$W_{LFG,CH4}$	Fraction of the volume of landfill gas that is methane	Fraction	Estimated under Division 2.3.6 of the NGER (Measurement) Determination.	For the purpose of equation 7, average values for a time interval not greater than 1 hour must be paired to measurements of $Q_{LFG,h}$ for the time interval.
				Frequency—continuously.	Otherwise, the measurements must be paired to measurements of $Q_{LFG,h}$ for the same measurement interval
				Measured at the same conditions as $Q_{LFG,h}$	Landfill gas contains moisture, typically from 2% to 7% on a mass basis. Flow measurement is usually done on the moist gas, but concentration measurement using a gas chromatograph is done on dried gas (because the instrument cannot handle moisture). Because water has a molecular weight different from methane and air components such as nitrogen and oxygen, multiplying the moist flow rate times the dry methane concentration will not give an accurate methane flow rate; it will be overstated by the 2% to 7% range referred to above. The Methodology is silent on how this is to be handled.

Further assessment of each of the parameters is assessed as follows:

$Q_{En\ h}$ – Energy content of the landfill gas sent to combustion device h

The energy content of landfill gas using equation 9 is estimated under Division 2.3.6 of the NGER (Measurement) Determination or section 6.5 using measurement criterion AAA. Either of these approaches follows widely applied measurement techniques.

$O_{h,a}$ – Operation of combustion device h during hour a

If the combustion device is a flare, operation is determined continuously or continually depending on the type of UV or temperature sensor in use. The 2015 Methodology in section 5 requires "the combustion process ... [be one] which can be monitored on a minute by minute basis", and in section 33 item 2 requires if temperature is measured then temperature must be "500 degrees Celsius or higher for 40 minutes or more in an hour". Similarly, the 2012 Methodology requires in section 3.18 "If flare operation is detected using temperature measurement, then the flare is taken not to be operational and the destruction efficiency taken to be zero in any particular hour if there is no record of the temperature of the exhaust gas of the flare or the recorded temperature is less than 500°C for any period exceeding 20 minutes in that hour."

Verification of these requirements is made difficult by the almost universal use of data loggers which record parameters such as temperatures each (typically) 10, 15 or 20 minutes. It is unclear whether, for example, a failure (less than 500 degrees Celsius) of two temperature values 10 minutes apart should result in a loss of claim for that hour. All that is certain is that (for this example) the temperature was unsatisfactory for some time around each of the time points ten minutes apart, and likely for between 10.1 and 29.9 minutes. Verification usually involves the creation of an algorithm such as 'fail if any two -10 minute data values are below 500°C'. The algorithm details are usually debated between the auditors and the proponents.

The effect of these issues is unlikely to be material to the abatement calculations but should be considered from a technical verification perspective.

For all other combustion devices, operation for each minute is to be determined in accordance with the manufacturer's specifications. If the device operates according to manufacturer's specifications for the entire hour then $O_{h,a} = 1$, otherwise $O_{h,a} = 0$. This effectively means that if a combustion device does not operate for a small length of time (seconds or minutes) then zero (0) operating time is recorded for that hour. This is likely to lead to an underestimation of calculated abatement.

$Q_{LFG\ h}$ – Landfill gas sent to combustion device *h*

The energy content of landfill gas using equation 8 is estimated under Division 2.3.6 of the NGER (Measurement) Determination using measurement criterion AAA, which is appropriate and an accurate measurement approach.

$Q_{EG,h}$ – Electricity (supplied to the grid or used on site) generated by internal combustion engine *h*

Electricity generated from internal combustion engines is estimated under Part 6.1 of the NGER (Measurement) Determination. This follows widely applied industry standards and is appropriate.

Since this only measures the electricity produced from the combustion of landfill gas (not from the combustion of other fuel types) there is a detection risk if other fuels are used by the engine but not appropriately recorded. For example, diesel or natural gas could be used for start-up fuel and would therefore need to be excluded from the abatement calculations.

$W_{LFG,CH4}$ – Fraction of the volume of landfill gas that is methane

The methane fraction of landfill gas is estimated under Division 2.3.6 of the NGER (Measurement) Determination. Landfill gas contains moisture, estimated for one ERF project as ranging on a 95% confidence interval from 2.3% (gas at 23°C in winter) to 7.5% (gas at 38°C in summer) on a molar (and therefore approximately on a volume) basis[32]. Flow measurement is usually done on the moist gas, but concentration measurement using a gas chromatograph is done on dried gas (because the instrument cannot handle moisture). Because water has a molecular weight different from methane and air components such as nitrogen and oxygen, multiplying the moist flow rate times the dry methane concentration will not give an accurate methane flow rate it will be overstated (by in the case above the 2.3% to 7.5% range referred to). The Methodology is silent on how this is to be handled.

Conclusion 16 Measuring requirements are defined as being consistent with NGER (Measurement) Determination specifications and in turn with relevant standards such as the *National Measurement Act 1960*. This is considered to be scientifically and technically robust as Australian Standards must be adhered to. The Methodology clearly specifies these requirements and makes references to external sources in an accurate and appropriate way.

3.2.1.2 Data Collection

The 2015 Methodology does not summarise the data collection requirements in the same level of detail as the 2012 Methodology (Division 3.3). However, these requirements are implicit in compliance with the Methodology (i.e., for a verifiable project, it is necessary to perform measurements and collect data as specified in the Methodology).

Conclusion 17 As the 2015 Methodology does not clearly specify the data collection requirements it can be concluded that they are not adequately specified.

3.2.2 2012 Methodology considerations

As previously mentioned, the 2012 Methodology (Division 3.3) provide more detail on the data collection requirements than the 2015 Methodology. Moreover, the requirements are considered scientifically/technically robust in general. Parameters that are outlined in section 3.14 (measurement procedures and measurement frequency) are assessed as follows:

$Q_{sent,h}$ – Quantity of landfill gas sent to a combustion device *h*

This is equivalent to $Q_{LFG,h}$, under the 2015 Methodology and must be measured by a flow meter, corrected to standard conditions. Data is required to be aggregated monthly and yearly using continuous measurement frequency which is scientifically robust.

[32] The water content of the landfill gas has been estimated using a computerised simulation used by Australian universities and gas companies, with data from an ERF project, and reported in unpublished "Equations for Water Content and Properties of Gas", Prof V. Rudolph, 06 May 2013.

DE – Methane destruction efficiency for device *h*

In most cases, it is expected that projects would apply the 0.98 default factor. Nevertheless, with enclosed flares and internal combustion engines, there is the option to perform measurement by a NATA accredited emission stack testing company. This must use a methodology based on the US EPA Method 18[33]. This would be expected to produce more accurate results than using the default value however, as a project can choose whether to measure DE or use the default factor, there is a risk of 'gaming' (i.e., applying the more beneficial destruction efficiency). It is noted that under the 2015 Methodology, the destruction efficiency has been changed to use the default values only.

W_{CH4} – Methane fraction in the landfill gas

Gas composition analysers are widely used in landfill gas collection systems and may be used in ERF projects, but are not compulsory. Under the 2012 Methodology, it is possible to apply the default methane concentration of 50%. Whilst this is likely to be a reasonable estimate, it is possible to operate a flare with methane concentrations lower than 40. Measuring the methane concentration is better than using a default value but either approach is quantifiable and verifiable.

Electricity (Q_{elec}) – Quantity of electricity used for abatement activity

The electricity used can be measured using the relevant meter and sub-meter values, or estimated from the invoiced amount of electricity supplied to the landfill. The use of submeter data is likely to be more accurate than estimates from invoiced amounts. With either approach, there are complications in assessing how much electricity is used by the abatement activity and other landfill activities unless appropriate sub-metering is in place. Nevertheless, electricity use is not expected to be a material amount in relation to the total abatement calculated in projects.

Fuel used (Qi) – Quantity of fuel used for abatement activity

For each fuel used for abatement activities, the amount of fuel must be estimated as a proportion of the total fuel used for the facility. The estimation can be made using readings from a meter or from invoices which is a robust approach scientifically. Manufacturer's specifications must be used to estimate the proportion of total fuel used for the facility. Consequently, the quantity of fuel used is expected to be reasonably accurate.

E_{Ph} – Quantity of electricity produced by combustion in internal combustion engine generator *h*

Electricity produced metered data can be used in the Methodology. This data can either be:

- electricity exported to the grid; or
- meter data from an internal combustion engine generator (if electricity is used onsite).

Since the accuracy of the meter used must be equivalent to a revenue meter (i.e. used for commercial transactions). This is considered to be technically sound and would meet the highest industry standards.

[33] US Environmental Protection Agency, Air Emission Measurement Center (EMC), Method 18 Measurement of gaseous organic compound emissions by gas chromatography, retrieved from: https://www.epa.gov/emc/method-18-volatile-organic-compounds-gas-chromatography.

Electrical efficiency factor (Eff) – The electrical efficiency factor of the internal combustion engine generator

The Eff can be determined by either:

- as specified by the internal combustion engine manufacturer (with reference to Australian Standard AS 4594.1 or equivalent); or
- using the default value of 36% (factor of 0.36).

Electrical efficiency can vary between different engine types, how well they are operated and maintained, and the load factor at which they are operated. All engines would be expected to have a technical specification, therefore it is not clear why the use of a default value of 36% would be appropriate (refer to section 4.1.3.3). It is understood this default value comes from the GGAS landfill gas methodology and that it is conservatively high. Most landfill gas engines are less efficient than 36% and therefore require more gas to generate the same quantity of electricity, resulting in a decreased number of ACCUs generated for a given number of MWh.

Volumetric measurement — Quantity of landfill gas ($Q_{lfg\ h}$) and methane fraction (W_{CH4}), flow computer requirements, and gas composition

Sections 3.15 to 3.17 of the 2012 Methodology follow robust scientific methods and adhere to commonly applied national and international standards. The description of quantity of landfill gas, methane concentration, and flow computer requirements are adequately specified and use references to external sources in an accurate and appropriate way.

Instruments must be calibrated to manufacturer specifications. Nevertheless, manufacturers generally do not specify calibration frequency for flow, temperature and pressure instruments. Furthermore, specifications may not be fully valid for landfill gas conditions (e.g. landfill gas can be moist, contain dirt particles and microbiological content).

Operation of flares

Methodology considerations in the case of operation of flares is addressed in section 3.2.1.1.

3.2.3 Measurement methods and the use of default values

The primary measurement methods used in the landfill gas Methodologies include:

- Measurement of methane sent to a combustion device (flow and concentration).
- Measurement of energy content of landfill gas sent to combustion device.
- Measurement of electricity produced by a landfill gas engine.

There are also several parameters within the landfill gas methods where default factors can be used.

- Default methane percentage.
- Destruction efficiency of flares and engines.
- Global warming potential of methane.
- Energy content of landfill gas.
- Oxidation factor.
- Electrical efficiency of engines (for electricity generation).

The use of default factors is common is many carbon abatement calculations. However, the choice of default values can impact the calculated abatement. It is therefore important that where default values are required that these are appropriate both scientifically and technically. These considerations are assessed for the most important default factors as follows:

3.2.3.1 Default methane percentage

Please refer to section 2.2.1.1 for background information. Whilst verification of the mathematical impact of the use of a 50% factor is straightforward, audit to reasonable assurance level of this parameter is challenging. Furthermore, a qualified opinion may be issued where the default 50% methane concentration is being used, when an average methane content may be below that value.

3.2.3.2 Oxidation factor

The oxidation factor of 10% is aligned with the Clean Development Mechanism (CDM), however the evidence is inconclusive if this is appropriate as discussed in section 4.1.3. More detail can also be found in section 4.1.5.4.

3.2.3.3 Other default factors

Verification of the mathematical impact of the use of the other five default factors (i.e. destruction efficiency of flares and engines, GWP of methane, energy content of landfill gas, oxidation factor and electrical efficiency of engines) is straightforward. Audit to reasonable assurance level of these parameters is also generally straightforward. Because the default values follow international guidelines or NGER Act determinations, they are considered appropriate.

3.2.3.4 Non-Carbon Tax percentage

Please refer to section 2.2.3 for background information. Verification of the exclusion of emissions from waste deposited during the carbon tax years is challenging if historical waste tonnes records are incomplete or lack credibility (e.g. if the data presents large increases or decreases from year to year).

3.2.3.5 Baselines

As noted in section 3.1.1.1, verification of baselines can be time consuming and present a detection risk as it may not be possible to review all relevant regulatory requirements. Refer to section 4.2 for more information.

<u>Conclusion 18</u> There are some differences and similarities between the 2012 and 2015 Methodologies. The areas of least rigour are:
a) The ability to use a default concentration of 50% (if measurement not already in use in the 2015 Methodology, and at any time in the 2012 Methodology).
b) Electrical efficiency can vary between different engine types, how well they are operated and maintained, and the load factor at which they are operated. All engines would be expected to have a technical specification. The default value of 36% is likely to be conservative and therefore appropriate.
c) Instruments must be calibrated to manufacturer specifications. Nevertheless, manufacturers generally do not specify calibration frequency for flow, temperature and pressure instruments. Furthermore, specifications may not be fully valid for landfill gas conditions (landfill gas can be moist, contain dirt particles and microbiological content).

Conclusion 19 The calculations set out in both the 2012 and 2015 Methodology allow the abatement delivered by the project to be quantified through the use of scientific measurements. Equations used vary depending on the project type so the use of calculations is tailored to different projects. The volume of landfill gas sent to a destruction device is measured by scientifically robust devices. The process of then converting landfill gas to volume of methane and amount of methane destroyed is also robust as this uses common methods for destruction efficiency. This excepts the use of some of the default values. In general, the default values are conservative and do not have a material influence on calculated abatement.

Conclusion 20 The Methodologies clearly set out the equations and how these should be applied to quantify the volume of landfill gas sent to destruction devices.

Conclusion 21 By reviewing the Methodologies, it can be concluded that the measurement and monitoring requirements refer to external references where appropriate and required.

3.3 Whether reasonable steps have been taken to minimise uncertainty in measurement and data collection associated with the method.

The Methodology has clearly taken reasonable steps to minimise uncertainty in measurement and data collection. Most measurement requirements are relatively straightforward and reduce uncertainty (e.g. gas flow measurements need to be within strict uncertainty limits). With the measurement of gas flow and methane concentration there is some inherent uncertainty as specified by manufacturer measurement devices.

In the 2012 Methodology, the measurement of landfill gas must be carried out using equipment that complies with the following accuracy and transmitter requirements:

a) Pressure < ±0.25%.

b) Differential Pressure < ±0.25%.

c) Temperature < ±0.50%.

The 2015 Methodology does not specify the accuracy and transmitter requirements. However, this can be derived from the relevant standards and manufacturer specifications. The requirements in both the 2012 and 2015 Methodologies to perform regular calibrations of gas flow meters and continuous methane analysers ensures that uncertainty is minimised for landfill gas measurement. However, as concluded above (refer to section 3.2.1), manufacturers usually do not specify calibration frequency for flow, temperature and pressure instruments, and any specifications may not be fully valid for landfill gas conditions which could lead to uncertainty.

Landfill gas contains moisture, estimated for one ERF project as ranging on a 95% confidence interval from 2.3% (gas at 23°C in winter) to 7.5% (gas at 38°C in summer) on a molar (and therefore approximately on a volume) basis[34]. Flow measurement is usually done on the moist gas, but concentration measurement using a gas chromatograph is done on dried gas (because the instrument cannot handle moisture). Because water has a molecular weight different from methane and air components nitrogen and oxygen, simply multiplying the moist flow rate times the dry methane concentration will not give an accurate methane flow rate; it will be overstated (by in the case above the 2.3% to 7.5% range referred to). The Methodology is silent on how this is to be handled.

There are other aspects of the abatement calculations that could add to the uncertainty of the calculations. These have been discussed above and include the following:

- Destruction efficiency – use of default value of 1 or 0.98 for engines and flares respectively.
- Proportion of landfill gas that is methane – use of default value of 50%.
- Oxidation factor – use of default factor of 10%.
- Electrical efficiency factor– use of default factor of 36%.
- There are some uncertainties that are inherent within the NGER (Measurement) Determination which are unavoidable, such as the methane's GWP or its calorific value.
- The measurement of non-carbon tax percentage, due to the project proponent being unable to control the data and often having to employ estimation techniques as landfills do not always keep the most consistent waste data.

Conclusion 22 The Methodology has taken reasonable steps to minimise uncertainty in measurement and data collection. Most measurement requirements are relatively straightforward and reduce uncertainty (e.g., gas flow measurements need to be within strict uncertainty limits). With the measurement of gas flow and methane concentration there is some inherent uncertainty as specified by manufacturer measurement devices. There is some uncertainty with the use of each of the default factors, particularly the default methane concentration.

3.4 Whether any reporting requirements in the method are clearly specified.

Part 5 Division 1 of the 2015 Methodology lists the information that must be included in project reports. This is reasonably clear, however, some additional guidance could be provided to project operators so that full details are included in offsets report, such as:

- compliance with different aspects of the Methodology; and
- details of the abatement calculations performed and source data to be provided/referenced.

Based on understanding obtained from projects there is limited guidance on the level of detail required in the offsets report. Therefore, it is likely that some projects will provide very detailed reports, whilst others will report on the minimum required.

[34] The water content of the landfill gas has been estimated using a computerised simulation used by Australian universities and gas companies, with data from an ERF project, and reported in unpublished "Equations for Water Content and Properties of Gas", Prof V. Rudolph, 06 May 2013.

3.4.1 2015 Methodology considerations

The offsets report requirements in the 2015 Methodology could be expanded to include specific details that are required to be assessed by the CER. Examples include project details, process flow diagrams, equipment specifications, parameters used, source data, abatement calculations, and other information as specified in the Methodology.

The current reporting requirements mean that a wide range of offsets reports are produced which is likely to increase the regulatory burden as additional information may be required by the CER if this is not clear in the offsets report. Conversely, too much information will require additional time for the verification and regulatory assessment.

An example in the 2015 Methodology where the reporting requirements are not clearly specified is the inclusion of the abatement calculations within the offsets report. For most projects, this would be intuitive to include, however the Methodology does not actually specify this within Part 5 Division 1. The limited detail included in the Methodology can create difficulties in verification, as the auditor is providing an opinion that the project report has been prepared in accordance with section 76 of the CFI Act. Section 76 (4) outlines the offsets report requirements which states that:

"An offsets report about a project for a reporting period must:

(a) be given in the manner and form prescribed by the regulations; and

(b) set out the information specified in the regulations; and [...]

(d) be accompanied by such other documents (if any) as are specified in the regulations [...]".

Conclusion 23 The 2015 Methodology reporting requirements are not clearly specified, for example it does not state that the abatement calculations, parameters, and data sources need to be included in the offsets report. It is therefore recommended that these are more clearly specified so that project managers know what level of detail is required, and so there is a more standardised and common approach to reporting. Of the projects reviewed there is an apparent variability in reporting, this supports the conclusion that the reporting requirements are not clearly specified.

3.4.2 2012 Methodology considerations

The 2012 Methodology does provide more specific reporting requirements, which are summarised as follows:

Information that must be included in an offsets-report

(1) The following information is required to be included in the first offsets report for a project to which this Methodology Determination applies:

(a) carbon dioxide equivalent net abatement amount for the project;

(b) the proportion of methane generated from the landfill that is required to be captured and destroyed to meet regulatory requirements (A_{reg});

(c) justification for the proportion of methane generated from the landfill that is required to be captured and destroyed to meet regulatory requirements;

(d) if applicable, the total volume of methane sent to combustion devices, in cubic metres (sum of $Q_{sent,h}$) and total volume of methane destroyed by combustion devices, in cubic metres (sum of $Q_{com,h}$);

(e) if applicable, the quantity of methane destroyed as a consequence of an internal combustion engine, in tonnes CO_2-e ($A_{com,ice}$);

(f) total amount of fuel and/or electricity used by the project, in kilolitres (kL), cubic metres (m^3), or kilowatt hours (kWh);

(g) destruction efficiency of each combustion device (DE_h);

(h) electrical efficiency (Eff) of the internal combustion engine generator (with reference to Australian Standard AS 4594.1 or equivalent);

(i) if applicable, the date of a report required under section 19 or section 22G of the *National Greenhouse and Energy Reporting Act 2007* and the factors and parameters used in that report, as prescribed in the *NGER (Measurement) Determination* or *NGER Regulations*.

These requirements are streamlined and do not require much information to be included in the offsets report. This can lead to difficulties during verification as the offsets report is unlikely to include all the information required to demonstrate compliance with the Methodology. Nonetheless this is more detailed than within the 2015 Methodology.

Conclusion 24 There is a risk with the 2015 Methodology that, as the reporting requirements are limited, not all the information would be required to be kept under the record-keeping requirements (sections 192 and 193 of the CFI Act require records to be kept if this is used in preparing the offsets report). If the offsets report does not specify much detail, then it is possible that the project proponent may not retain all the required information necessary to demonstrate compliance with the Methodology. This is a potential issue when it comes to the verification of methodology compliance.

3.5 Whether record keeping requirements in the method, in combination with record keeping requirements in the Act and legislative rules (which apply to all projects), would enable an auditor to verify the abatement calculations (including all inputs to calculations) and confirm that all requirements in the method have been met.

The record keeping requirements in the CFI Act, legislative rules and the methods should enable an auditor to verify the abatement calculations. Although as described above (refer to section 3.4.1), the abatement calculations are not specifically required in the 2015 Methodology offsets report. Nonetheless, there are several requirements which require a significant amount of data to be logged and retained which allows for verification. How this information is retained and presented is likely to impact the time required for verification.

For the audit of ERF projects, the auditor is required to assess overall compliance with the Methodology. Specifically, the auditor is required to provide reasonable assurance that, in all material respects:

- the proponent meets requirements of the relevant Methodology determination under subsection 106(3) of the CFI Act,
- the project report(s) has been prepared in accordance with section 76 of the CFI Act, and
- the project has been operated and implemented in accordance with the:
    - section 27 declaration,
    - relevant Methodology determination, and
    - requirements of the CFI Act.

Since the project is to be operated and implemented in accordance with the relevant CFI Methodology Determination, this requires the auditor to assess compliance with all parts and sections of the Methodology. This requires going through each part of the Methodology, assessing the relevance to the project and using the evidence retained by the project proponent to verify compliance. This is not always apparent to individual projects, and as such the CFI Methodology Determination or explanatory statements could include an additional description of the type of evidence to be retained.

Conclusion 25 Record keeping requirements in the 2015 Methodology do not include all information required to demonstrate compliance with the Methodology in full. As the auditor is verifying compliance with the whole Methodology the record keeping requirements could be specified in additional detail to assist with the verification process.

The record-keeping requirements in the Act are defined as follows:

In section 192 - Record-keeping requirements—preparation of offsets report

Scope

(1) This section applies if a person:

(a) made a record of particular information; and

(b) used the information to prepare an offsets report.

Record-keeping requirements

(2) The regulations may require the person to retain:

(a) the record; or

(b) a copy of the record;

for 7 years after the offsets report was given to the Administrator.

In section 193 - Record-keeping requirements—methodology determinations

Scope

(1) This section applies if:

(a) a person is the project proponent for an eligible offsets project; and

(b) under the applicable methodology determination, the person is subject to a record- keeping requirement relating to the project.

Sections 192 and 193 can be interpreted as any information recorded that is used in preparing the offsets report should be retained. As such, it is important that the information to be included in the offsets report is clearly defined within the CFI Methodology Determination. Otherwise, there is a risk that when it comes to verification not all the required information to assess compliance with the Methodology is available. Examples within the landfill gas Methodology include:

- the historical waste data from the landfills (used to determine legacy waste and non-carbon tax proportions), and
- evidence supporting the determining of baseline abatement.

In determining the baseline abatement, the auditor would require access to relevant information such as landfill licenses, environmental permits, local authority and State regulations, etc. Whilst this type of information should be readily available at the landfill, if the requirement is not specifically noted, this may lead to difficulties during verification.

3.5.1 Calculation requirements

The offsets report should present the calculated abatement. Additionally, all supporting information is expected to be retained and either included in the offsets report or referenced. For example, all relevant parameters and equations should be clearly justified and any measured or monitored data recorded for verification. The calculations and monitored parameters are clearly defined in the Methodology and under sections 191 to 194 of the CFI Act, the project proponent must comply with the monitoring requirements.

Record-keeping requirements outlined in the 2012 Methodology under section 4.4 are very detailed, and require records to be kept for general information, combustion device information, monitoring device information, data required on the direct and indirect measurement, and legacy waste proportion data. This in combination with the detail specified in the offsets report requirements means that the 2012 Methodology should allow the auditor to verify the abatement calculations and confirm that all requirements in the Methodology have been met.

Conclusion 26 Record-keeping requirements, as defined in the CFI Act, require project proponents to retain records if they are used in the preparation of the offsets report. There are some gaps in the specific detail to be included in offsets reports that could lead to required information not being recorded. Furthermore, if the reporting and record-keeping requirements do not cover all aspects of the Methodology, then it could be difficult for an auditor to verify that all requirements in the Methodology have been met.

Conclusion 27 In the 2015 Methodology, the abatement calculations should be verifiable (i.e. the project must provide the required data to support each parameter and assumption used in the equations). However, the record keeping requirements (when compared to the 2012 Methodology) are very limited in detail and do not explicitly specify the records that must be kept. In contrast, section 4.4 of the 2012 Methodology is very specific in the record keeping requirements. As such, the 2012 Methodology is more straightforward to verify than the 2015 Methodology.

3.6 Whether record keeping requirements in the method provide sufficient flexibility to accommodate different types of evidence available to proponents

As described in section 3.5 of this report, record keeping requirements in the 2015 Methodology are not clearly defined. However, the different types of evidence available to proponents are limited for most data requirements. This means that whilst there is some flexibility to proponents in the evidence required, for many of the required parameters, the source data is likely to only be in one format (e.g. gas flow data, methane concentration, electricity generation, etc.).

Similarly, for compliance with aspects of the Methodology such as the calculations and baseline assessment, the project proponent will be required to justify the assumptions and data used. This information needs to be provided to the auditor for verification.

There are limited aspects to this Methodology where flexibility in the evidence provided is available. This is presumably one reason why the record keeping requirements are not overly specific - the calculation requirements cover most of the evidence that is required.

As the 2015 Methodology is not specific about the different types of evidence that can be used, the project proponent may use different types of evidence available, for example:

- *supporting justification for the baseline assessment*; there may be more than one source of information used to justify the baseline, depending on whether the project is a transitioning, upgrade or new project, and, if it is a new project, the source of the estimate for the regulatory proportion. Furthermore, evidence related to the option chosen - essentially including all documents relied upon - will need to be supplied. The options, as specified in Schedule 1 of the Methodology are:
    - Reference to State or Territory guidelines for landfilling.
    - Asking the environmental regulator what gas capture rate is needed to comply.
    - Asking the environmental regulator whether the current gas capture rate is compliant.
    - Determined by an independent expert.
- *historical landfill waste composition data*; different landfills are likely to have different systems and processes for recording waste received; and
- *non-monitored data*; the proponent might be able to utilise different types of evidence to support assumptions when equipment or instruments fail.

In contrast, the 2012 Methodology's record-keeping requirements (section 4.4) are quite specific, and could reduce the flexibility in the types of evidence available. Nonetheless, the 2012 Methodology enables a more straightforward audit process (i.e. verification).

<u>Conclusion 28</u> There are differences between the 2012 and 2015 Methodologies regarding the record keeping requirements. The 2012 Methodology has relatively detailed and specific record keeping requirements which potentially reduce the flexibility in the type of evidence available to proponents. However, this is likely to make the verification process more straightforward. Contrastingly, the 2015 Methodology has limited record-keeping requirements, which increases the flexibility in evidence requirements, but can potentially create more issues in the verification process.

<u>Conclusion 29</u> There are not many aspects of the CFI Methodology Determination where the type of evidence has much flexibility, i.e., equipment and instrument data obtained from the monitored parameters is likely to only be derived from one source. Hence, whilst there could be some flexibility, the methods are prescriptive in the data that is required for the abatement calculations.

4 Assessment of whether the method is supported by clear and convincing evidence

Summary:

This section explores whether the landfill Methodology is supported by clear and convincing evidence. This was done via a detailed assessment of the Methodology and supporting relevant information sources (e.g. NGER Measurement Determination, CDM, etc.) and relevant literature in the subject.

4.1 Whether there is clear and convincing evidence to support

Clear and convincing evidence can be defined as being supported by relevant scientific results published in peer-reviewed literature (see paragraph 133(1)(d) of the Act). The response to this requirement therefore focuses on the available literature that is relevant to addressing each sub-requirement.

This section considers the following requirements:

- The scope of activities and circumstances covered by the method, section 4.1.1;
- The calculation approaches used, section 4.1.2;
- The appropriateness, accuracy and scientific validity of monitoring, measurement and data collection requirements, section 4.1.3;
- The inclusion and exclusion of emissions sources that are a direct consequence of the project including on the grounds of materiality, section 4.1.4; and
- The appropriateness and conservativeness of all estimates, assumptions, and projections, section 4.1.5.

4.1.1 The scope of activities and circumstances covered by the method

In both, the 2015 and 2012 Methodologies, the scope of the activity and circumstances covered by the landfill gas Methodology is landfill gas that is destroyed over and above regulatory requirements that are eligible for ACCUs. The clearest evidence to support ACCUs being issued for additional landfill gas abatement is the continued use and support of the CDM landfill gas Methodology.

The United Nations Framework Convention on Climate Change (UNFCCC) supports landfill gas abatement as being eligible for carbon credits and is now operating under version 18.0[35]. The Methodology mirrors the CDM methodology in most regards, with additional regulatory baseline determinations tailored to the Australian regulatory environment. Whilst the CDM continues to support landfill gas destruction, there is clear and convincing evidence that the ERF landfill gas methodology scope and circumstances are supported.

[35] UNFCC, (2017) Flaring or use of landfill gas v18.0, 4 May 2017. Accessed on 16/08/17, available from: https://cdm.unfccc.int/UserManagement/FileStorage/0X2IE6B1PJDLKMWN89AZGTFUHR3VYS.

Conversely to the CDM, the Landfill Directive in the European Commission (EC) places strict requirements on the collection of landfill gas[36]. Annex I of the EC Landfill Directive defines the requirements for gas control as provided below:

> *4. Gas control*
>
> *4.1 Appropriate measures shall be taken in order to control the accumulation and migration of landfill gas (Annex III).*
>
> *4.2 Landfill gas shall be collected from all landfills receiving biodegradable waste and the landfill gas must be treated and used. If the gas collected cannot be used to produce energy, it must be flared.*
>
> *4.3 The collection, treatment and use of landfill gas under paragraph 4.2 shall be carried on in a manner which minimises damage to or deterioration of the environment and risk to human health.*

In essence, the Landfill Directive states that landfill operators must maximise the amount of landfill gas that they collect[37]. In Europe, landfill operators are required to recover the maximum amount of energy from the landfill gas over the whole lifecycle of the landfill. It is noted that the best available techniques should be applied. The following utilisation techniques have been applied successfully:

- Introduction of the treated methane into the gas mains.
- Combined heat and power utilisation.
- Direct use of the gas as a fuel.
- Electricity generation.

If it is not possible or economically infeasible to generate energy, then landfill operators in Europe are required to flare the gas. In many European member States, this has been common practice for over two decades, and it therefore could be argued that landfill gas capture is common practice in many developed countries. As such, in Europe, the additionality of landfill gas flaring could be questioned.

There are slight differences between the 2012 and the 2015 Methodologies that impact the scope of activities covered. These differences are highlighted in the below sections.

4.1.1.1 2015 Methodology considerations

Under the 2015 Methodology, the scope of activities and circumstances covered is restricted to projects that reduce GHG emissions by collecting and combusting landfill gas. A landfill gas project may be:

a) a new project (section 9 of the Methodology); or

b) a recommencing project (section 10 of the Methodology); or

c) an upgrade project (section 11 of the Methodology); or

d) a transitioning project (section 12 of the Methodology).

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[36] EC, (2013) Landfill Gas Control -Guidance on the landfill gas control requirements of the Landfill Directive. Accessed on 16 August 2017 from:
http://ec.europa.eu/environment/waste/landfill/pdf/guidance%20on%20landfill%20gas.pdf

[37] EC, (1999) Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste. European Commission (EC). Accessed on 16 August 17, from:
http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31999L0031

Each of the project requirements defined in Part 3 of the Methodology clearly defines the scope of activities and circumstances for a project to generate ACCUs. All projects must collect landfill gas through a landfill gas collection system at a landfill and combust the gas using a combustion device.

4.1.1.2 2012 Methodology considerations

The scope of activities and circumstances covered by the 2012 Methodology (section 1.3) includes the following types of landfill legacy emissions avoidance projects:

a) transitioning Greenhouse Friendly projects;

b) transitioning GGAS projects; and

c) projects that involve the following activities:

   (i) installing, on or after 1 July 2010, a landfill gas extraction system; and

   (ii) collecting gas emitted from legacy waste from the landfill facility; and

   (iii) combusting the methane component of the gas using a combustion device to chemically convert it to carbon dioxide (CO_2).

In the application of the 2012 Methodology 'installing a landfill gas extraction system' does not include the reinstallation, or replacement of, upgrades to, or modifications of an existing system, where such systems were installed prior to 1 July 2010 (refer to Figure 7 for a graph of project volumes by year.) A project under the landfill gas 2012 Methodology that is not a transitioning project must include the installation of a new system, in entirety, where no system has previously been installed.

Part 2 of the 2012 Methodology further defines the requirements that must be met for an offsets project to be eligible. In addition to the above defined landfill legacy emissions avoidance projects, the projects must relate to the capture and combustion of emissions from legacy waste only (i.e. credits are not issued for solid waste containing biodegradable organic matter accepted by a landfill facility after 1 July 2012). Furthermore, the proportion of methane that is required to be captured or destroyed to meet regulatory requirements must be calculated in accordance with the relevant guidelines (refer to section 2.4.1.2) or specific landfill licence requirements (refer to section 2.4.1.3) for calculating regulatory baselines. The scope of activities and circumstances covered by the 2012 Methodology is therefore restricted.

4.1.1.2.1 Transitioning Greenhouse Friendly and GGAS projects

Greenhouse Friendly was the program administered by the Commonwealth Government. GGAS was the New South Wales Government's Greenhouse Gas Reduction Scheme and the Australian Capital Territory Government's Greenhouse Gas Abatement Scheme. Both Greenhouse Friendly and GGAS projects were included in the Department of Environment's *Positive List* contained in the Carbon Credits (Carbon Farming Initiative) Regulations 2011. This means the activity is an emissions avoidance activity and such projects are not subject to permanence obligations. The Australian Government reviews the *Positive List* periodically with a view to keeping the list current considering technological developments and the latest scientific research.

4.1.1.2.2 New projects

A new project is required to:

- install, on or after 1 July 2010, a landfill gas extraction system; and
- collect gas emitted from legacy waste from the landfill facility; and
- combust the methane component of the gas using a combustion device to chemically convert it to carbon dioxide (CO_2).

There is peer-reviewed literature that demonstrates the combustion of landfill gas will reduce GHG emissions through the conversion of methane (CH_4) to carbon dioxide (CO_2), in consideration of each gas' GWP. If a landfill has no regulatory requirement to collect and combust methane, then this provides a basis for defining the scope of activities that allow projects to generate ACCUs.

4.1.2 The calculation approaches used

The calculations employed in the Methodology follow the same general format of the CDM Methodology, but are adjusted for the Australian regulatory and measurement environment. Landfill gas project methodologies under the CDM were first published in 2004, and the approach is well tested and widely adopted[38].

Calculations in the Methodology do differ from the CDM methodology, as the scope of the former is more limited than the latter (such as not allowing for emission reductions for displaced fossil fuel generated electricity from the grid). In addition, the Methodology needs to accommodate NGER requirements such as the non-carbon tax waste percentage, which the CDM methodology does not consider. However, the combination of the similar calculations of the CDM methodology adjusted for NGER and the Australian regulatory environment do provide clear and convincing evidence for the support of the calculations used.

Section 3.1 describes the calculations for both the 2015 and 2012 Methodologies. The calculation approaches under both Methodologies follow robust scientific approaches with additional regulatory baseline assessment being underpinned by Federal and State Government legislation (refer to section 4.2).

4.1.2.1 2015 Methodology considerations

The calculations in the 2015 Methodology are underpinned by peer-reviewed scientific literature. For example, the NGER (Measurement) Determination sections that are referred to in the Methodology are all based on a rigorous scientific method that follows national and international standards for measurement of greenhouse gases. The origins and source references used are not well documented within the Determination itself. However, these should be well known by the DoEE and are comparable to methodology approaches used in other jurisdictions.

The deduction of baseline abatement from project abatement is underpinned by the CDM and the additionality test required under the CFI Act.

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[38] UNFCCC, (2004) Flaring or use of landfill gas v1.0, 2 Sept 2017. Accessed on 16/08/17 and available from: https://cdm.unfccc.int/UserManagement/FileStorage/eb15repan1.pdf

4.1.2.2 2012 Methodology considerations

The calculations in the 2012 Methodology follow peer-reviewed scientific literature. Emissions from the project and regulatory requirements are deducted from the emissions avoided as a consequence of the project (refer to section 4.1.4).

4.1.3 The appropriateness, accuracy and scientific validity of monitoring, measurement and data collection requirements

The monitoring, measurement and data collection requirements in the 2015 and 2012 Methodologies are similar. Both methods require certain parameters to be monitored and measured. The most important (i.e. material) parameters are summarised and assessed in Table 14. In general, the monitored and measured data collected is considered appropriate. The data collected and used in the abatement calculations follow a scientific approach and is sufficient to calculate ACCUs. It is understood that the development of the NGER (Measurement) Determination has gone through a robust scientific peer review process.

Most of the parameters outlined in Table 14 are underpinned by clear and convincing evidence (i.e. the measurements follow widely adopted national and international calculation methods commonly used in industry). For example, the CDM requires similar approaches for measurement, monitoring and data collection.

The measurement of mass flow of a GHG in a gaseous stream is underpinned by the CDM's methodological tool that is based on the fundamentals of thermodynamics[39] and drying[40]. Unlike most commercial gas streams in pipelines (such as natural gas and compressed air), landfill gas contains moisture, estimated for one ERF project as ranging on a 95% confidence interval from 2.3% (gas at 23°C in winter) to 7.5% (gas at 38°C in summer) on a molar (and therefore approximately on a volume) basis[41]. Flow measurement is usually done on the moist gas, but concentration measurement using a gas chromatograph is done on dried gas (because the instrument cannot handle moisture). Because water has a molecular weight different from methane and air components such as nitrogen and oxygen, multiplying the moist flow rate times the dry methane concentration will not give an accurate methane flow rate; it will be overstated by, in the case above, the 2.3% to 7.5% range referred to. The Methodology is silent on how this is to be handled.

Compliance with requirements for monitoring of parameters is important as this underpins the correct calculation of abatement credited by the project. Monitoring requirements (section 33 of the 2015 Methodology) include the process for monitoring and the standard to which monitoring must occur. In some cases, a project may be unable to monitor a parameter to the requirements specified. When this occurs, section 34 of the 2015 Methodology requires that adjustments be applied for the time intervals that the parameters are not being monitored in accordance with requirements (termed the non-monitored period). The adjustment is necessary to ensure that all estimates or assumptions

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[39]Van Wylen, G.J., Sonntag, R.E. and Borgnakke, C. (1994), Fundamentals of Classical Thermodynamics, Fourth Edition, John Wiley & Sons, Inc.

[40] Strumillo, C. and Kudra, T. (1986), Drying: Principles, Applications and Design, Gordon & Breach Science Publisher; Montreaux, Switzerland.

[41] Rudolph, V. (2013), The water content of the landfill gas has been estimated using a computerised simulation used by Australian universities and gas companies, with data from an ERF project, and reported in unpublished "Equations for Water Content and Properties of Gas", 06 May 2013.

used in the Methodology are conservative and are in accordance with the offsets integrity standards outlined in section 133 of the CFI Act.

The main exceptions to potential deviations from scientific validity are where the use of default factors is allowable. As such, the use of default factors may cause uncertainty and may not always be conservative, and therefore appropriate. Further description of these parameters is provided in the following sub-sections.

Table 14: Key parameters required to be measured and monitored

Description	Unit	Parameter		Measurement method
		2012	2015	
Quantity of landfill gas sent to a combustion device (h)	m^3	$Q_{sent,h}$	$Q_{LFG,h}$	Continuously measured by a flow meter, corrected to standard conditions. Section 3.15 of the 2012 Methodology provides the requirements for volumetric measurement. Same approach as described in the 2015 Methodology and defined in Division 2.3.6 of the NGER (Measurement) Determination using measurement criteria AAA.
Methane destruction efficiency for device h	%	DE_h	DE	DE can be measured (but not required) in the 2012 Methodology by a National Association of Testing Authorities (NATA) accredited emission stack testing company, using a method based on US EPA Method 18. However, the 2015 Methodology requires the use of default values.
Methane fraction in the landfill gas	m^3CH_4 / m^3 landfill gas	W_{CH4}	$W_{LFG,CH4}$	Under the 2012 Methodology, measured in accordance with section 3.15. Under the 2015 Methodology, estimated under Division 2.3.6 of the NGER (Measurement) Determination. Alternatively, the default value of 0.5 from section 5.14 (c) of the NGER (Measurement) Determination can be used in each method.
Quantity of electricity used for abatement activity	kWh	Q_{elec}	N/A	Measured using the relevant meter and sub-meter or estimated from the invoiced amount of electricity supplied to the landfill.
Quantity of fuel used for abatement activity	kl or m^3	Qi	N/A	For each fuel used the amount must be estimated (from meter or invoice) as a proportion of totals for the facility.
Quantity of electricity produced by methane combustion in internal combustion engine generator (h)	MWh	E_{Ph}	$Q_{EG,h}$	Meter data equivalent to a revenue meter must be used (highly accurate).
Electrical efficiency factor of the internal combustion engine generator	%	Eff	Eff_h	Uses the manufacturer specification or can use 0.36 default value derived from 2.38(2)(a)(ii) of the NGER (Measurement) Determination.
Energy content of the landfill gas sent to combustion device h	GJ	E_{lfg}	$Q_{En,h}$	The 2012 Methodology requires the use of flow computer and Schedule 1, Part 2 of the NGER (Measurement) Determination. In the 2015 Methodology, estimated under Division 2.3.6 or section 6.5 (using measurement criteria AAA) of the NGER (Measurement) Determination.

4.1.3.1 Methane destruction efficiency (DE)

The default methane destruction efficiency for a combustion device of 0.98 in the 2015 Methodology is based on the use of an enclosed flare. This is the most usual arrangement for safety and control reasons.

The 2012 Methodology also allows the use of 0.98 but does give the option to measure the methane destruction efficiency. It is therefore likely that projects will select the most beneficial value in terms of total ACCUs. Consequently, allowing the option to measure (or use default value for DE) may not always be conservative or appropriate (i.e. the proponent would most likely select the default value if it was more beneficial to ACCUs generated).

The default methane DE for an internal combustion engine device in the 2015 Methodology is 1.00. This appears reasonable for large internal combustion engines such as electricity generators. Nonetheless, consideration should be given to research performed in Germany on uncombusted methane from internal combustion engines that shows all engines have some methane slip which can vary at different scales, see Figure 10.

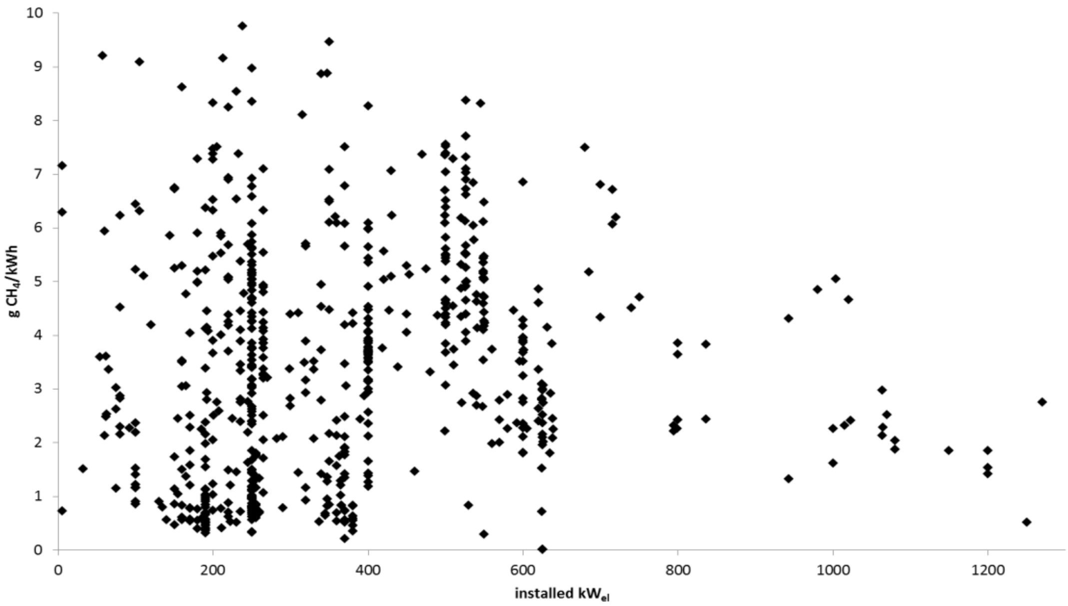

Figure 10: Uncombusted methane emissions from biogas engines in Germany (Clemens et al, 2014)[42]

4.1.3.2 Methane fraction in the landfill gas

The default methane percentage is set at 50% which is the same as the CDM. The reference for the 50% values appears to be derived from Intergovernmental Panel on Climate Change (IPCC) 2006 guidelines for national greenhouse gas inventories. This represents a reasonable and potentially conservative average estimate. Nevertheless, it is possible to operate a flare with methane concentrations lower than 40%. Low methane concentrations can occur, particularly towards the end of the methane generation cycle from a waste body.

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[42] A review of methane loss in engines from combustion of biogas in Germany, in Clemens et al, (2014). The diagram is taken from the presentation “Experiences from Emission Analysis as a Tool for Plant Optimization”, held by Dr Joachim Clemens, bioanalytic GmbH, Troisdorf at the IBBA Methane emission workshop in Kiel, Germany on 4 September 2014.

Gas composition analysers are widely used in landfill gas collection systems and may be used in ERF projects, but are not compulsory. As mentioned in section 2.2.1.1, once a project has used measurement, it must continue to do so under section 24(3) of the 2015 Methodology. However, if the project commences using the default value it can continue to be used indefinitely. Projects still using the 2012 Methodology can change to and from the default factor as they wish.

The use of default values for methane concentration may therefore not always be supported by clear and convincing evidence. A key risk is that air may be added to the landfill gas collection system which would increase the flow of landfill gas whilst reducing the methane concentration. As such, projects would benefit from using the default value of 50%.

There are projects that are known to not measure the gas composition. This can be done either on a continuous basis or a periodic sample basis using hand held gas analysers or bag samples. Nonetheless, the Methodology does not stipulate that this data is required to be used which could lead to an over estimation of calculated abatement. From a reasonable assurance perspective, it would be questionable why you would measure methane concentration as less than 50% but then use the default value of 50%.

4.1.3.3 Electrical efficiency of the internal combustion engine

Under both the 2012 and 2015 Methodologies, it is allowable to use the default electrical engine efficiency of 36% which is a commonly used value. All engines would be expected to have a technical specification. Even though the variability of the landfill gas composition will dictate this efficiency, (i.e. the composition of landfill gas will vary in amounts of methane and carbon dioxide which may mean the manufacturer specification cannot always be accurately used).

The gas composition can vary with different methane concentrations and trace gases likely to affect the electrical efficiency of the internal combustion engine. Off-grid engine and gas turbine systems have different default efficiencies depending on the nominal capacity of the power generation unit. An example from the CDM is provided in Table 15.

Table 15: Default efficiency for off-grid power plants[43]

Location	Nominal capacity of power plants (CAP, in kW)						
Generation Technology	CAP≤10	10≤CAP≤50	50≤CAP≤100	100≤CAP≤200	200≤CAP≤400	400≤CAP≤1,000	CAP>1,000
Reciprocal engine system (e.g. diesel, fuel oil, gas engines)	28%	33%	35%	37%	39%	42%	45%
Gas turbine systems	28%	32%	34%	35%	37%	40%	42%

This shows that the electrical efficiency increases with the engine capacity. It also demonstrates the expected variation in efficiency. Since all engines should have a technical specification it would be anticipated that should be used. The impact of the engine efficiency assumption is assessed in section 5.

4.1.4 The inclusion and exclusion of emissions sources that are a direct consequence of the project including on the grounds of materiality

Activities that must be accounted for abatement calculations in the 2012 Methodology are shown in Figure 11 and include:

- grid-derived electricity and/or fuel used in the process of gas capture and combustion. For example, the electricity and fuel used to power pumps and engines used in the operation of flares, as well as in the operation of control and monitoring systems;
- supplemental fuel, for example; natural gas, if used to sustain combustion of landfill gas in a flare or combustion engine. Where emissions are generated by the combustion process, and fugitive emissions from the incomplete combustion of the methane and the generation of nitrous oxide during the combustion process;
- landfill gas that is captured and destroyed by an internal combustion engine to generate electricity; and
- landfill gas that is captured and destroyed via an open or enclosed flare.

[43] UNFCC, (2017) Flaring or use of landfill gas v18.0, 4 May 2017. Accessed on 16/08/17, available from: https://cdm.unfccc.int/UserManagement/FileStorage/0X2IE6B1PJDLKMWN89AZGTFUHR3VYS

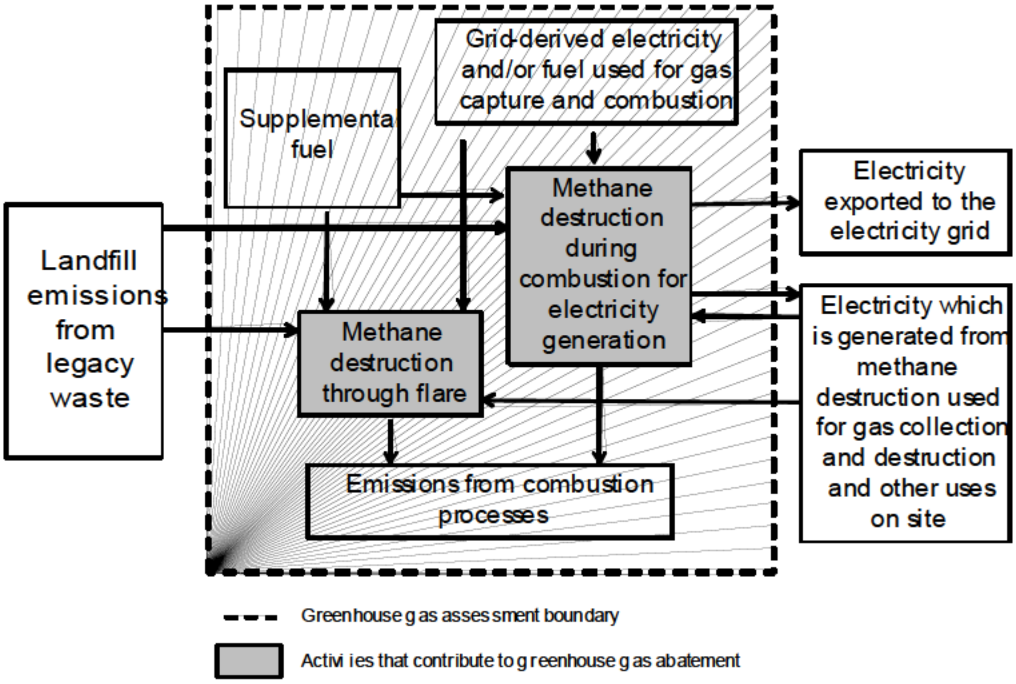

Figure 11: Flow diagram - GHG assessment boundary for an abatement activity (2012 Methodology)[44]

The GHG assessment boundary does not include the GHG emissions from landfill waste, as it is not required for the purpose of calculating the abatement from the methane captured and destroyed. However, an estimate of the emissions from the landfill waste is required for the purpose of calculating the proportion of methane generated from legacy waste (and for the carbon tax fraction in the 2015 Methodology).

The 2012 Methodology includes project emissions from electricity and fuel use. Based on projects we have obtained information on, it is understood that these emissions are not expected to be material in relation to the total calculated abatement. A high level check of the projects would show that electricity and fuel use are likely to be moderate in relation to the total flow of landfill gas and methane. Moreover, as methane has a higher GWP than carbon dioxide. it is apparent that emissions from fuel combustion would have to be significant to materially impact the calculated abatement.

The 2015 Methodology does not include the GHG emissions from electricity and fuel use which demonstrates that these emissions can be excluded from the project boundary to simplify the method.

Emissions from combustion of the landfill gas (e.g. N_2O and CH_4) have been excluded from the 2015 Methodology (previously included in the 2012 Methodology) presumably on the basis that they do not have a material impact on the total calculated abatement, which is reasonable.

[44] Clean Energy Regulator (undated), "Participating in the Emissions Reduction Fund: A guide to the capture and combustion of methane in landfill gas from legacy waste method" (2012 Methodology).

Additional potential emission sources include:

- Electricity: monitoring and measurement equipment is expected to use electricity. Nevertheless, GHG emissions from electricity use would not be material (<1%) in relation to the total methane flows.
- Start-up fuel: flares and internal combustion engines may require start-up fuel (e.g. diesel, LPG or natural gas). Nonetheless, a very small amount of fuel would be used before switching to landfill gas.

The inclusion and exclusion of major sources follows a similar format to the CDM methodology. It is therefore deemed appropriate. The materiality threshold has led to the removal of some smaller emission sources from the calculation. For example, the emission of nitrous oxide (N_2O) during the combustion of landfill gas has been removed from the abatement calculation under the ERF which is conservative. It is noted the materially threshold was employed to simplify the ERF landfill gas in the 2015 Methodology compared to the 2012 Methodology. Given the removal of emission sources such as nitrous oxide are less than 1% of the emissions stemming from the project, it is considered appropriate given the materiality threshold employed.

The GHG emissions assessment boundary does not include reductions in carbon dioxide emissions caused by displacing electricity derived from fossil fuel. This is not an eligible source of abatement for crediting under the ERF. This is considered a valid approach since it would require a consequential modelling approach which would not been appropriate at the individual project level[45]. Furthermore, the electricity generation component is covered by the RET.

GHG emissions from electricity used for gas capture and combustion are not included in the GHG emissions assessment boundary where that electricity is created using methane and combusted on-site. This is because the emissions from the combustion process are already included in the GHG emissions assessment boundary.

Carbon dioxide emissions associated with the generation and combustion of landfill gas are biogenic. This means that, biological capture balances over a sufficiently short time, such that release of carbon dioxide can be considered to have no net impact on atmospheric GHG levels. Thus, these emissions are not included in the GHG emissions assessment boundary which is common practice in GHG emissions accounting.

4.1.5 The appropriateness and conservativeness of all estimates, assumptions, and projections

4.1.5.1 Monitoring parameters

Compliance with requirements for monitoring of parameters is important to ensure that abatement credited by the project is calculated correctly. Monitoring requirements (refer to Table 14) include the process for monitoring and outline the standard to which monitoring must occur.

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[45] Plevin, R., Delucchi, M. & Creutzig, F. (2013) "Using attributional Life Cycle Assessment to estimate climate-change mitigation benefits misleads policy makers, J. Ind. Ecol., 18 (1), 73-83.

In some cases, a project may be unable to monitor a parameter to the requirements specified. When this occurs, section 34 of the Methodology requires that adjustments be applied for the time intervals that the parameters are not being monitored in accordance with requirements (termed *the non-monitored period*). The adjustment is necessary to ensure that all estimates or assumptions used in the Methodology are conservative and in accordance with the offsets integrity standards outlined in section 133 of the CFI Act.

For parameters listed in item 1 of the table in subsection 34(1) of the Methodology (i.e. $W_{LFG,CH4}$), the consequence for not monitoring in accordance with the requirements is to use the default emissions factor for that parameter. This is considered conservative as is included in the lower order monitoring option for the parameter. Furthermore, the proponent need to apply a 10 per cent adjustment to the default emissions factor (i.e. the factor is multiplied by 0.9) for a period of up to three (3) months in any 12-month period. For any period in excess of these three (3) months, then the adjustment is 50 per cent (i.e. the factor is multiplied by 0.5).

For parameters listed in item 2 of the table, (i.e. $Q_{En,h}$, $Q_{LFG,h}$ and $Q_{EG,h}$) the consequence for not monitoring these parameters in accordance with the monitoring requirements is for the proponent to make a conservative estimate of the parameter for the duration of the non-monitored period.

The need for a proponent to apply section 34 arises from failure to meet monitoring requirements. When section 34 is used, the project will be required to include information relating to the monitoring failure in its offsets report for the relevant reporting period (set out in section 31). This is to provide the CER with evidence that will allow them to determine the nature, and frequency, of the failure to meet the monitoring requirements of the Methodology. The approach taken for non-monitored periods should be conservative otherwise ACCUs will not be issued which is appropriate.

4.1.5.2 Baseline determination

As depicted in section 2.2.4, the baseline determination is one of the main estimates and assumptions included in the abatement calculations. This is determined following legislative and regulatory published information. However, it is not apparent that this is based on clear and convincing peer-reviewed scientific evidence. Different landfill gas projects may receive different baselines. The baseline applied to a project is the main factor when assessing the risk of under- or over-crediting. If a baseline is too high, a project would not be credited ACCUs for abatement additional to regulatory requirements, and may mean the project does not go ahead. By contrast, if a baseline is too low, a project will receive ACCUs for abatement that would have occurred regardless because of regulatory requirements. This is further assessed in section 4.2.

4.1.5.3 Landfill gas calculator

Refer to section 2.5.2 for a discussion on the landfill gas calculator and its use in the exclusion of emissions from waste deposited during the carbon tax period. Modelling emissions from solid waste deposited at a landfill as several uncertainties, however the use of the NGER landfill emissions calculator is required and therefore is appropriate. There is no evidence to suggest that this calculator is not conservative.

4.1.5.4 Methane oxidation factor

As landfill gas passes through the landfill cover or cap, methanotrophic bacteria oxidise some of the methane. The extent of oxidation varies with the type and thickness of cover material, moisture levels, temperature and the gas flux rate[46,47,48]. The IPCC (2006) guidelines sets a default value of zero for national greenhouse gas inventories but indicates that a value of 10% may be appropriate where landfills are well managed. The Australian national inventory uses the 10% value and requires this in NGERS reporting. All but one of the reviewed life cycle assessments (LCAs) put oxidation factors to 10%.

Methane oxidation rates can be estimated in laboratory experiments and *in situ* through carbon isotopes measurements in gases below and above the cap. This work shows that oxidation greater than 10% are readily possible. A literature review[49] concludes that up to 30% could be expected. Another, more recent literature review[50] of 42 studies found a mean oxidation factor value of 36% and only four reporting values of 10% or less. In clayey soil covers the average oxidation factor was 18%. The field studies, on average, had a lower oxidation factor than the laboratory studies, probably because "cracks and fissures … in the field allow some CH_4 to bypass oxidation[51]".

4.1.5.5 Non-carbon tax percentage

Emissions of landfill gas start a year after waste deposit and continue for occur over a long period, based on the model set by the NGER (Measurement) Determination. For example, based on this Methodology, a Victorian landfill that accepted an equal quantity of waste during the carbon tax years, only 2.3% of the emissions would have arisen during those years.

There does not appear to be sufficient and appropriate peer-reviewed scientific evidence to support the inclusion of the non-carbon tax percentage estimation, however the calculations used in the landfill gas model are considered to be appropriate.

Where landfills report under NGER, this calculation is not overly difficult, as the required information is already collected and collated, and such landfills are familiar with the solid waste calculator. For smaller sites that do not report under NGER, however, the data requirements are onerous.

4.1.5.6 Historical waste data

The project participant must report annual tonnages, and the proportional split across waste type, since the landfill opened. The project proponent does not generally have access to this historical data, and it is often incomplete, based on low quality estimates, and difficult to compile to a standard acceptable to auditors.

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[46] Streese, J. and Stegman, R., (2003) Design of biofilters for methane oxidation. In Proceedings of Sardinia.
[47] Gómez, K.E., Gonzalez-Gil, G., Lazzaro, A. and Schroth, M.H., (2009) Quantifying methane oxidation in a landfill-cover soil by gas push–pull tests. Waste Management, 29(9), pp.2518-2526.
[48] Schuetz, C., Bogner, J., Chanton, J., Blake, D., Morcet, M. and Kjeldsen, P., (2003) Comparative oxidation and net emissions of methane and selected non-methane organic compounds in landfill cover soils. Environmental science & technology, 37(22), pp.5150-5158.
[49] Jensen, J.E.F. and Pipatti, R., (2002) CH_4 emissions from solid waste disposal, background paper on good practice guidance and uncertainty management in national greenhouse gas inventories.
[50] Chanton, J.P., Powelson, D.K. and Green, R.B., (2009) Methane oxidation in landfill cover soils, is a 10% default value reasonable?. Journal of Environmental Quality, 38(2), pp.654-663.
[51] Ibid. p.658.

When considering the question of the conservativeness of assumptions used in the calculation of the non-carbon tax percentage this is difficult to assess as it applies the same modelling to both carbon tax and non-carbon tax years. This produces a fraction that is applied to the calculated abatement. Overall, the removal of the carbon tax fraction can be considered conservative.

4.1.5.7 Other estimations, assumptions and projections

Other estimations and assumptions included in the Methodology have been discussed previously and include:

- methane concentration (sections 2.2.1.1 and 3.2.1.1),
- methane destruction efficiency (sections 2.2.1.4 and 3.2.2),
- electrical efficiency (section 3.2.2), and
- oxidation factor (section 3.2.3.3).

The effect of the conservativeness and appropriateness of these parameters is further assessed in Section 5.

> Conclusion 30 There are no apparent projections used under the landfill gas Methodology as it is reliant on direct measurement and calculations. When compared to other CFI/ERF methods (other than previously discussed estimations/assumptions) the landfill gas Methodology is considered to use appropriate and conservative values. Furthermore, wherever practical, these are aligned with NGER (Measurement) Determination methods which are comparable to other international methods such as the CDM.

4.2 Whether the 30 per cent default regulatory proportion defined in section 28 of the method is supported by clear and convincing evidence. The conclusion should be supported with reference to state and territory requirements for landfill gas capture.

Refer to section 2.2.4.2 for background information. Section 28 of the Methodology refers to the proportion of methane that would have been combusted without the project. It is divided into:

- New or recommencing project
- Upgrade project
- Transitioning projects

Each of these project types includes reference to the regulatory proportion:

- *$W_{B,Reg}$ means the regulatory proportion of the methane combusted during the reporting period that would have been combusted without the project as determined using Schedule 1 to this determination.*

Under the 2015 Methodology, the regulatory proportion is calculated with reference to Schedule 1 of the Methodology, which provides four options:

1. Reference to State or Territory guidelines for landfilling.
2. Asking the environmental regulator what gas capture rate is needed to comply.
3. Asking the environmental regulator whether the current gas capture rate is compliant.
4. Determined by an independent expert.

4.2.1.1 Option 1: Reference to State or Territory guidelines for landfilling

The State or Territory guidelines for landfilling are interpreted as setting limits for gas concentrations above the landfill. These levels are linked to a percentage gas capture rate through modelling. The modelling links methane generation (calculated using NGER methods) to concentrations above the landfill, using a model. The model is based on landfill surface area and the proportions of the surface area under different types of cover.

The authors of this report have not been able to assess all the source of information for this option (i.e. a transparent version of the CFI landfill methane regulatory baseline calculation). Nevertheless, its parameters appear to be appropriate and conservative.

Option 1 lists the applicable methane concentration limit and corresponding flux rates (as sourced from State and Territory guidelines and represent the most stringent requirement since 24 March 2011). These values could be specified by environmental regulators differently for the *final cover area* and *intermediate cover area* of a landfill. It is noted that the intermediate cover area is likely to be more permeable and temporary than the final cover area. These methane concentration limits and the corresponding flux rates may be updated periodically if applicable methane concentration limits become more stringent.

The documents that are the basis of the tables in subclauses 4(2) and 4(3) are:

- Queensland Department of Environment and Heritage Protection - *Guideline—Landfill siting, design, operation and rehabilitation.*
- NSW Environmental Protection Agency - *Environmental Guidelines: Solid Waste Landfills.*
- EPA Victoria - *Siting, Design, Operation and Rehabilitation of Landfills.*
- EPA South Australia - *EPA Guidelines: Environmental management of landfill facilities (municipal solid waste and commercial and industrial general waste).*
- EPA Tasmania - *Landfill Sustainability Guide.*
- Northern Territory EPA - *Guidelines for the siting, design and management of solid waste disposal sites in Northern Territory.*

Conclusion 31 In terms of whether the 30 per cent default regulatory proportion defined in section 28 of the Methodology is supported by clear and convincing evidence, the authors of this report have not been able to assess all the source of information that underpin that statistic. Nevertheless, the input parameters (which are available) appear to be appropriate.

5 ASSESSMENT OF WHETHER ESTIMATES, PROJECTIONS OR ASSUMPTIONS ARE CONSERVATIVE

Summary:

This section assesses the conservativeness of relevant estimates, projections or assumptions in the Methodology.

5.1 Whether all estimates, assumptions and projections used in the method are appropriate and conservative (i.e. the values are more likely to underestimate than over estimate abatement). Where one or more estimates, assumptions or projections are not conservative, whether the overall calculation of the net abatement amount is conservative.

In section 4.1.5, an assessment was performed of whether there is clear and convincing evidence to support the appropriateness and conservativeness of all estimates, assumptions, and projections used in the Methodology. Reference should therefore first be made to the previously answered requirement. To summarise the key estimates and assumptions included within the Methodology:

- Baseline abatement
- Landfill gas calculations and non-carbon tax percentage
- Methane fraction in the landfill gas
- Energy content of landfill gas
- Oxidation Factor
- Methane destruction efficiency
- Electrical efficiency of internal combustion engine
- Global warming potential of methane

Of the above estimates or assumptions, all can be considered appropriate and most are conservative. The following sub-sections further assess each of these and where relevant alternative assumptions are included in a sensitivity analysis.

5.1.1 Baseline abatement

The 30% default baseline previously discussed in section 2.2.4 and is considered to be conservative. It is not further assessed here.

5.1.2 Landfill gas (solid waste) calculator and non-carbon tax percentage

NGER calculations for emissions from landfills are well established and provide a common basis to assess the GHG emissions from landfill operations. The Solid Waste Calculator has been updated to reflect changes in the NGER legislation affecting the 2016-2017 reporting period.

Under the carbon price and subsequently the NGER calculations for emissions arising from solid waste deposited at landfills could be deemed to be conservative. As such, some of the assumptions in the landfill gas calculator for the decomposition rates (and hence methane generated) are reasonably likely to be conservative. This is expected, so that NGER reporters do not under-estimate emissions from landfill operations. Key assumptions within the solid waste calculator have not changed during the non-carbon tax years, hence when working out the fraction to be removed from calculated abatement, the modelling approach is the same. Further assessment on the appropriateness of the non-carbon tax percentage is included in section 2.2.

5.1.3 Methane fraction in the landfill gas

The methane fraction in landfill gas has a default value of 50% which is the same is in the NGER (Measurement) determination and as used in the CDM, it could therefore be deemed appropriate. Whether this is conservative or not will depend on the age and composition of waste deposited at the landfill. The amount of air drawn into the gas capture system will also impact the methane concentration. It is therefore possible that the default value is not always conservative. However, there will also be many circumstances where methane concentration in landfill gas is higher than 50% and can be as high as 60% or more. This would make the methane fraction conservative.

5.1.4 Energy content of landfill gas

The energy content of landfill gas is based on robust measurement methods as defined in the NGER (Measurement) determination. These can be considered to be conservative but also are likely to be an accurate measure of energy content as they are based on scientific methods.

5.1.5 Oxidation Factor

The oxidation factor provided in the NGER (Measurement) Determination subsection 5.4(1) is 0.1 (or 10%). It is unclear from the Determination what the reference or basis for this is, although we are informed that it is based on the IPCC's waste guidance. Regardless, it is an important estimate and assumption that is used in the abatement calculations. If, for example, a higher oxidation factor of 15% or 20% was assumed, then the calculated abatement could be over-estimated for the period that the methane destruction device is offline.

5.2 In giving consideration to the above, an assessment of the baseline calculations is required. In particular, the assessment should examine equation 12 of the method to determine whether it will result in a conservative estimation of abatement. Where a problem is identified the service provider should identify an appropriate solution.

The landfill gas project baseline abatement (net abatement) for the reporting period is determined using Equation 12 in section 28 (Part 4 Division 4) for the 2015 Methodology. The baseline abatement is the methane combusted during the project and generated by non-carbon tax waste, multiplied by the proportion of methane that would have been combusted without the project.

The baseline reduces the number of ACCUs the project receives, based on the volume of gas that would have had to be captured for regulatory purposes had the project not been accredited under the ERF.

The application of a baseline effectively forms part of the *regulatory additionality test*. It determines how many ACCUs can be created based on how much gas would need to be captured to meet regulatory requirements. It is noted that it is not possible to capture all the gas from a landfill (refer to section 6.2). Regulatory requirements for gas capture vary greatly between jurisdictions and between sites, as described in section 2.1.3.

The net abatement therefore requires:

a) determination of the regulatory proportion,

b) default baseline proportion and

c) baseline proportion.

The determination of the abovementioned proportions depends on the type of project, as shown in Figure 12:

- Equation 12 refers to equations 13 to 16, and
- Equation 14 refers to equations 17 to 19.

This is, the baseline abatement for the reporting period, in tonnes CO_2-e, is (***equation 12***):

$$A_B = M_{Com,NCT} \times W_B$$

where:

- $\boldsymbol{A_B}$ means the baseline abatement for the reporting period, in tonnes CO_2-e.
- $\boldsymbol{M_{Com,NCT}}$ means the methane combusted during the reporting period that was not generated from carbon tax waste, in tonnes CO_2-e, worked out using equation 3.
- $\boldsymbol{W_B}$ means the proportion of the methane combusted during the reporting period that would have been combusted without the project worked out using whichever of equations 13 to 16 applies.

For the proportion of methane that would have been combusted without the project, this is either:

A. For new or recommencing project

If the project is a new project or a recommencing project, the proportion of the methane combusted during the reporting period that would have been combusted without the project is worked out using the formula (***equation 13***):

$$W_B = Maximum(W_{B,Reg}, W_{B,Def})$$

where:

- $\boldsymbol{W_B}$ means the proportion of the methane combusted during the reporting period that would have been combusted without the project.
- $\boldsymbol{W_{B,Reg}}$ means the regulatory proportion of the methane combusted during the reporting period that would have been combusted without the project as determined using Schedule 1 to this determination.
- $\boldsymbol{W_{B,Def}}$ means the default proportion of the methane combusted during the reporting period that would have been combusted without the project, which is as follows:

  (a) 0% if the project proponent can demonstrate that, since 24 March 2011, the landfill concerned has not been subject to:

    (i) legislation or regulatory guidelines for landfill; or

    (ii) a licence condition or development approval that includes any form of general or specific qualitative requirement to collect, control, manage or limit landfill gas, methane odour or greenhouse gases;

  (b) otherwise—30%.

B. Upgrade project

If the project is an upgrade project, the proportion of the methane combusted during the reporting period that would have been combusted without the project is worked out using the formula (***equation 14***):

$$W_B = Maximum(W_{B,Reg}, W_{B,Def}, W_{B,Ex})$$

where:

- W_B means the proportion of the methane combusted during the reporting period that would have been combusted without the project.
- $W_{B,Reg}$ means the regulatory proportion of the methane combusted during the reporting period that would have been combusted without the project determined using Schedule 1 to this determination.
- $W_{B,Def}$ has the same meaning as in subsection (1).
- $W_{B,Ex}$ means the proportion of the methane combusted during the reporting period that would have been combusted without the upgrade project worked out using equation 17.

Equations 17 to 19 detail the proportion of methane that would have been combusted without upgrade.

C. Transitioning projects

If the project is a transitioning project that was operating under the Carbon Credits (Carbon Farming Initiative) (Capture and Combustion of Methane in Landfill Gas from Legacy Waste) Methodology Determination 2012 (the legacy determination), the proportion of the methane combusted during the reporting period that would have been combusted without the project is worked out using the formula (***equation 15***):

$$W_B = R_P$$

where:

- W_B means the proportion of the methane combusted during the reporting period that would have been combusted without the project.
- R_P means R_P as worked out under the legacy determination.

If the project is a transitioning project that was operating under the Carbon Credits (Carbon Farming Initiative) (Capture and Combustion of Methane in Landfill Gas from Legacy Waste: Upgrade Projects) Methodology Determination 2012 (the legacy upgrade determination), the proportion of the methane combusted during the reporting period that would have been combusted without the project is worked out using the formula (***equation 16***):

$$\mathrm{W_B} = \mathrm{B_P}\ W_B = B_P$$

where:

- W_B means the proportion of the methane combusted during the reporting period that would have been combusted without the project.
- B_P means B_p as worked out under the legacy upgrade determination.

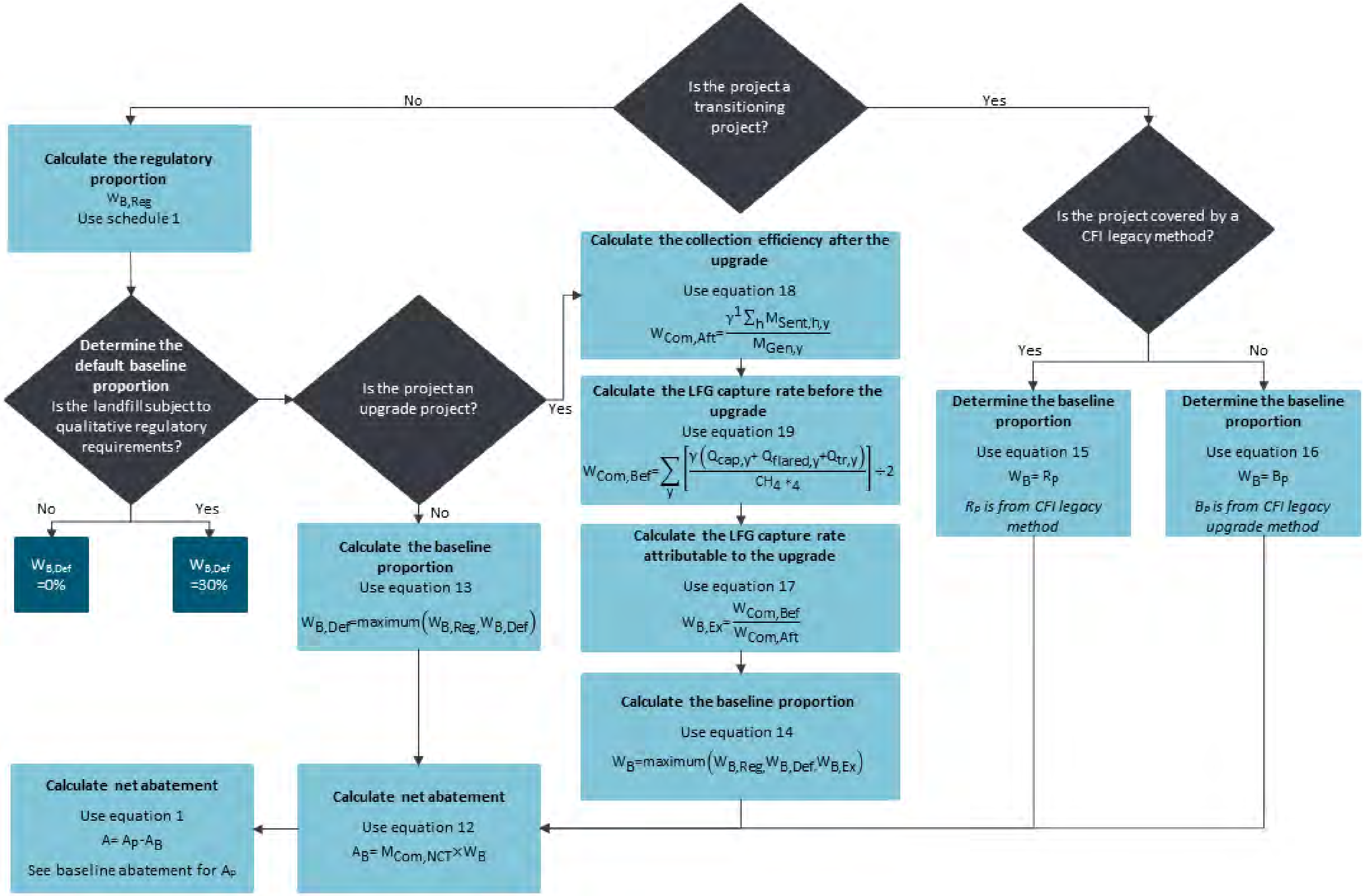

Figure 12: Equation flowchart – baseline abatement (CER, 2015)[52]

[52] Clean Energy Regulator (2015), "Participating in the Emissions Reduction Fund: A guide to the landfill gas method 2015", retrieved on 20 August 2017 from: http://www.environment.gov.au/climate-change/emissions-reduction-fund/methods/landfill-gas

This approach (i.e. Equation 12, referring to Equations 13 to 16, and Equation 14 referring to Equations 17 to 19), forms a logical and valid set of net abatement baseline equations. Equation 12 is straightforward, and Equations 13 to 19 are relatively straightforward, and the logic tests to determine which of these equations is applicable are clear. Whether the resulting baselines are conservative depends on which equation is used:

- The regulatory baseline (i.e. 0% or 30%) is reviewed in section 2.4.1 of this report.
- The case of a quantitative baseline (which may be over 50% if, for example; the landfill is in Victoria or the ACT) is reviewed in sections 2.2.4.3 and 2.5.1 of this report.
- In the case of previous CFI and upgrade projects (which represent the majority of ERF landfill gas projects as shown in Figure 13) whether the baselines are conservative is perhaps of limited relevance, because the 'grandfather' right to use those original baselines is not in question, at least for the initial crediting period. An analysis of those baselines would be useful, but would require baseline data from those projects.

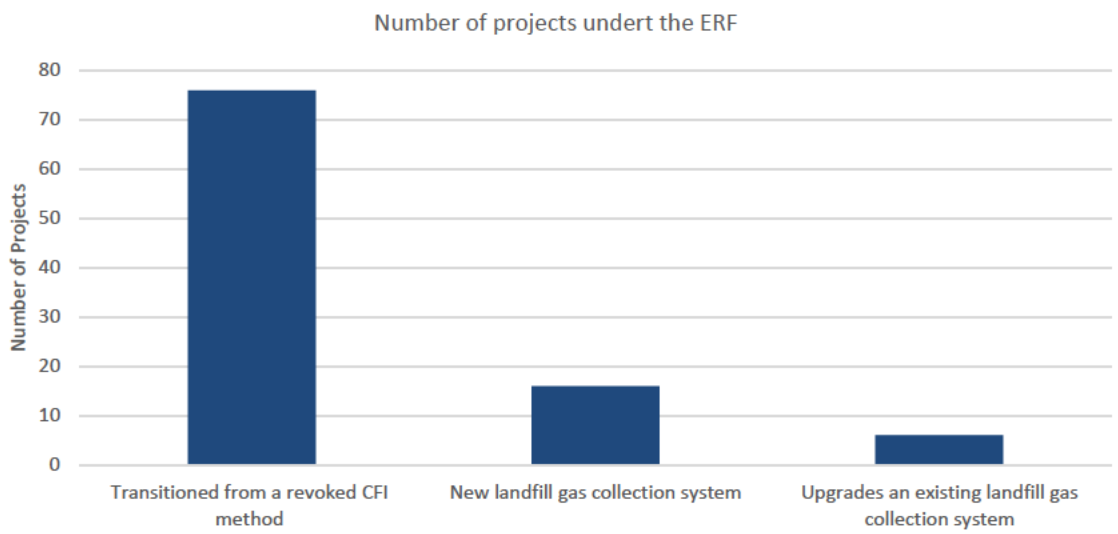

Figure 13: Numbers of landfill gas projects in the ERF project register (by type), 9 October 2017

<u>Conclusion 32</u> The baseline abatement can be quantified using the calculation approaches set out in equations 12 to 19 of the Methodology. These equations are straightforward and their logic is clear. The ongoing 'grandfathered' baselines for pre-existing CFI projects may or may not be conservative, but the ability to use them is a clear legislative right.

6 PROVIDE DATA AND AN ANALYSIS OF LANDFILL GAS CAPTURE AND COMBUSTION PROJECTS

6.1 For as many Australian landfills as reasonably possible, a table providing:

6.1.1 Landfill size (tonnes waste received per year and tonnes emissions in CO_2-e per year) and location (state and city/town)

Landfill size data (tonnes waste received per year) does not appear to be collected on a routine basis by either the Federal or State Governments. Therefore, to obtain this information it was necessary to conduct a detailed literature review to collate data for relevant landfill sites in Australia. This section provides the main findings and highlights from this literature review. Additional supporting information, assumptions, and data analysis is provided in a separate excel file provided to the DoEE (Annexe C).

Information on waste management facilities was obtained from the Australian Government (Geoscience Australia). The information considers different site types and include multi-purpose facilities, landfills, transfer stations and reprocessing facilities. A summary of this information is provided in section 6.1.1.1.

Furthermore, the Waste Management Association of Australia (WMAA) undertakes surveys of landfills in Australia. SMEC understands that surveys were undertaken in 2006-07; in 2008; and in 2010. The surveys were similar but extra questions were added each time. Response rates have varied. Relevant results from analysis of the landfill survey data are provided in section 6.1.1.2 as derived from the Blue Environment[53] report to the DoEE. It should be noted that this data is several years old and therefore some of this may be out of date (e.g. new and closed landfills). Nonetheless, it provides useful context to the landfills in Australia and highlights potential data gaps.

6.1.1.1 Waste Management Facilities in Australia

This data includes a total of 2,291 waste management facilities in Australia, as shown in Table 16. It is noted that the database accounts for all facilities in Australia, including:

- non-operational sites;
- different landfills in the same site (i.e. a site can account for multiple facilities); and
- considers sites which used to be a landfill and ceased landfilling activities but are operating transfer stations (i.e. considered as two different facilities).

As such, there are some differences with the data provided in section 6.1.1.2, in particular the NT and QLD.

[53] Blue Environment (2013). Analysis of landfill survey data. Prepared for WMAA. Available from: https://www.environment.gov.au/system/files/resources/91763f0e-f453-48d0-b33e-22f905450c99/files/landfill-survey-data.pdf

Table 16: Waste Management Facilities in Australia[54]

Site Type	Total	NSW	VIC	NT	WA	SA	QLD	TAS	ACT
Multi-Purpose	241	101	45	4	29	24	35	2	1
Landfill	1,166	263	156	140	254	109	226	17	1
Transfer Station	755	138	195	9	51	96	196	68	2
Reprocessing	129	53	36	1	10	7	14	1	7
Total Sites	2,291	555	432	154	344	236	471	88	11
% Landfill per State		*23%*	*13%*	*12%*	*22%*	*9%*	*19%*	*1%*	*0%*

Figure 14 provides a visual representation of geographic spread of waste management facilities. Landfills are diverse in size and are dispersed across Australia. It is noted that:

- Most the larger landfill sites are located near dense population areas which have higher rainfall levels.
- These landfills will have the greatest landfill gas production and potential for odour.
- These landfill sites are the most likely to have local community pressure to manage the landfill gas.

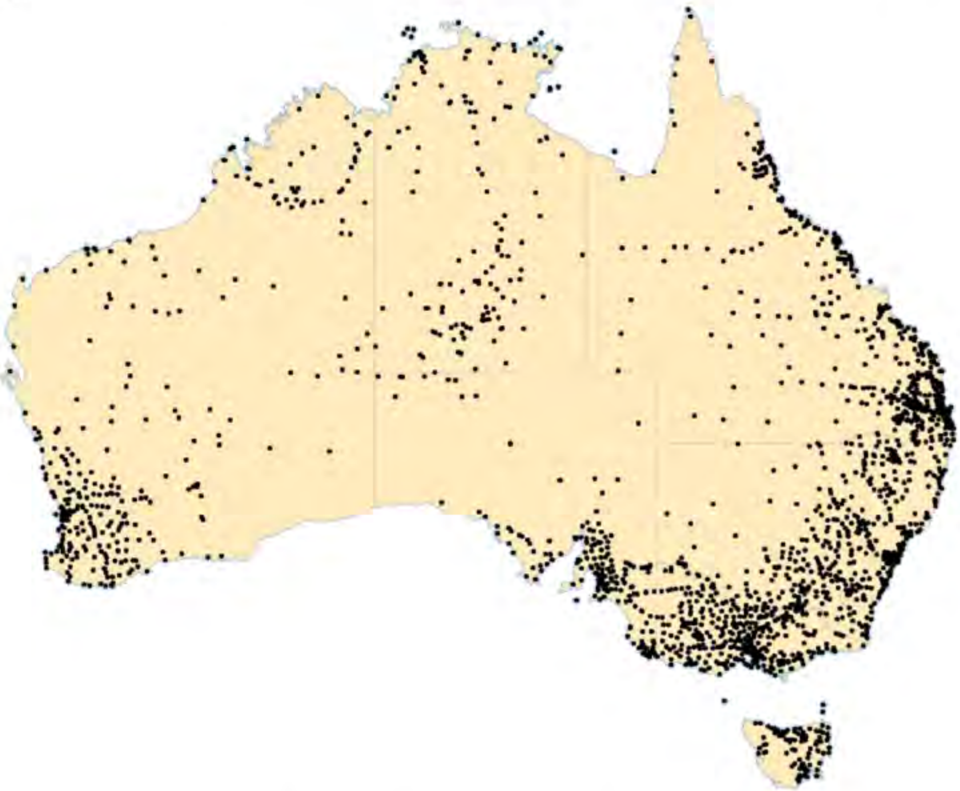

Figure 14: Waste Management Facilities location[55]

[54] Source: Australian Government, Geoscience Australia, 2017, Waste Management Facilities_v1.1.xls, downloaded from https://ecat.ga.gov.au/geonetwork/srv/eng/search#!a66ac3ca-5830-594b-e044-00144fdd4fa6 on 24 July 2017.

[55] Source: Australian Government, Geoscience Australia, 2017, Waste Management Facilities. Accessed on 24 July, 2017 from: http://www.ga.gov.au/metadata-gateway/metadata/record/72592/

6.1.1.2 Landfill sizes and distributions

Sites can be classified into size groups through reference to their reported annual inputs or through reference to the population serviced. Table 17 provides a summary of the clarification.

Table 17: Size classifications (Blue Environment, 2013)

Size class	Annual tonnes	Population serviced	Average tonnes/person in size class based on known data
Very small	≤1,000	≤250	0.19
Small	1,001 to 20,000	250 to 5,000	0.18
Medium	20,001 to 100,000	5,000 to 50,000	0.56
Large	≥100,000	≥50,000	0.48

The bulk of Australia's landfill sites are small or very small. Thirty-eight sites (8%) are known to be large and 78 (16%) are known to be medium. The 21% of unknown size are likely to be mostly small or very small (see Figure 15).

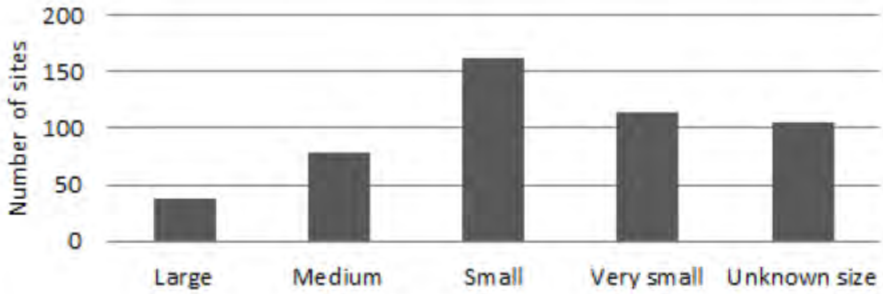

Figure 15: Reported numbers of Australian landfills by size class (Blue Environment, 2013)

Queensland reports the most sites, followed by New South Wales and Western Australia (refer to Figure 16). This is consistent with the land size and population distribution in each of these jurisdictions.

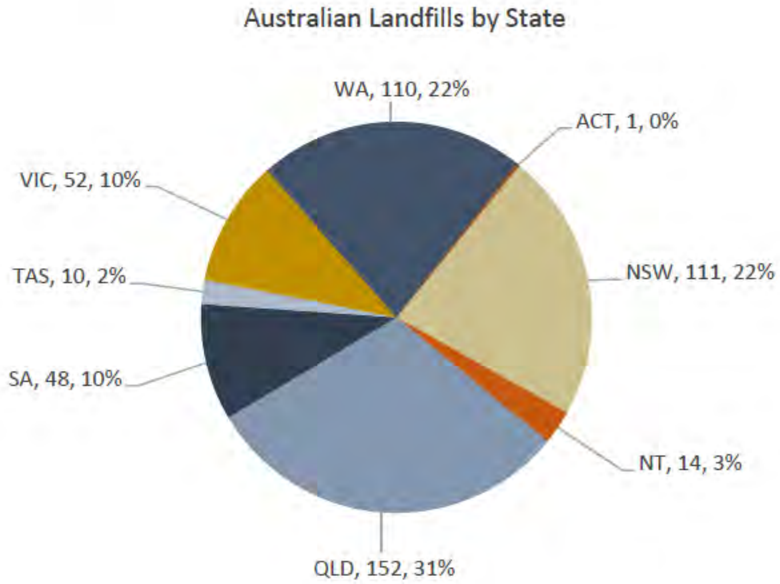

Figure 16: Reported numbers of Australian landfills by jurisdiction (Blue Environment, 2013)

Queensland, Western Australia and South Australia have relatively high proportions of small landfills. This matches their highly-dispersed populations. Victoria and Tasmania have a high proportion of large and medium sites. NSW has most large sites matching its relatively large population.

The 8% of Australia's landfills that are classified as large accept 75% of the waste. These are the sites servicing the major cities. Medium-sized landfills accept 20% of the waste, small sites receive 5% and the very small sites accept only 0.2%. This data is summarised by State in Table 18.

Table 18: Millions of tonnes received per year by jurisdiction & landfill size class (Blue Environment, 2013)

State	Large	Medium	Small	Very Small	All sizes
NSW & ACT	4.68	1.05	0.21	-	5.93
NT	-	0.07	-	-	0.07
QLD	3.33	0.87	0.26	0.01	4.47
SA	0.47	0.12	0.11	-	0.71
TAS	0.29	0.17	0.01	-	0.46
VIC	2.07	0.45	0.13	-	2.65
WA	1.72	0.58	0.13	0.01	2.44
Total	12.56	3.31	0.85	0.02	16.73

6.1.1.3 Landfill sizes and GHG emissions

The CER provided SMEC with data on landfill sites in Australia which included the 'facility name', 'state', and the 'total emissions from the landfill facility (tCO_2-e) per annum' from 2008-09 to 2015-16. This data is derived from NGER reporting and potentially data from State Governments.

In order to use this data, it was necessary to perform several manipulations, data cleansing, and a detailed assessment of the data quality and relevance. The steps taken to make the data presentable for the purposes of addressing this requirement can be summarised as follows:

1. Reviewed each facility to merge or remove any duplications. For example, some facilities are reported under different names in different years, hence this data was merged.
2. If a facility only has one year of reported data it was removed from further assessment as these appeared to be either anomalies, or were not considered to provide robust data. For example, there appears to be many facilities that have only reported in 2008-09, it is not clear why but could be to do with the introduction of NGER reporting.
3. To estimate the 'typical' emissions per year, an average of the available years was taken with outliers removed. It should be noted that several landfills have closed in this period, therefore their emissions profiles could be expected to change and hence historical data may not be fully reflective of current or future emissions (i.e. the landfill could be capped at the end of its life).
4. There are many landfill sites where data is reported in one or some years, but not all. This could be because:
    - the reporting threshold is not triggered, or
    - an issue with the data quality in prevalent.
5. From the data provided and our subsequent analysis of landfill gas combustion projects, it is apparent that the DoEE data is missing a lot of landfill sites. This could be because they are below reporting thresholds, or because the names of the gas combustion projects do not easily

correlate to the landfill name. Wherever possible we have matched the emissions data with other relevant data on the landfill (see sections 6.1.2 and 6.1.3).

SMEC was provided with emissions data for 273 landfills. This was filtered down to remove outliers such as a single reported year or where sites needed to be merged (as reported under more than one name). This gave a total of 75 landfills with reasonable emissions data of 2 or more years. All of these landfills were researched using online searches to try and ascertain the tonnes of waste received per year. Of the 75 landfills, it was found that 22 had data on waste received, 15 had closed, 6 were mines, and for the remaining 39, the annual tonnages received at the landfill were unknown.

For the landfills with data, Figure 17 shows the annual average GHG emissions per year (tCO_2-e) compared to the tonnes of waste received for the 22 landfill sites analysed. This data can be further analysed to estimate the GHG emissions per tonne of waste received:

Annual average GHG emissions compared to tonnes of waste received per year

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Figure 17: Annual average GHG emissions compared to tonnes of waste received per year (22 landfills)

Analysis of this data shows a reasonable correlation between landfill size and scope 1 GHG emissions. This is in line with expectations as larger landfills have more waste and bigger surface area, hence fugitive emissions would likely be higher.

Another metric assessed is the ratio of GHG emissions divided by the tonnes of waste received. This gives an indication of the relative GHG emissions of different sized landfills, as shown in Figure 18. To obtain this data the 22 landfill sites were categorised into those receiving less than 100 kt/yr, 100-300 kt/yr, and greater than 300 kt/yr. These tonnages relate to the small/medium, large, and very large size respectively.

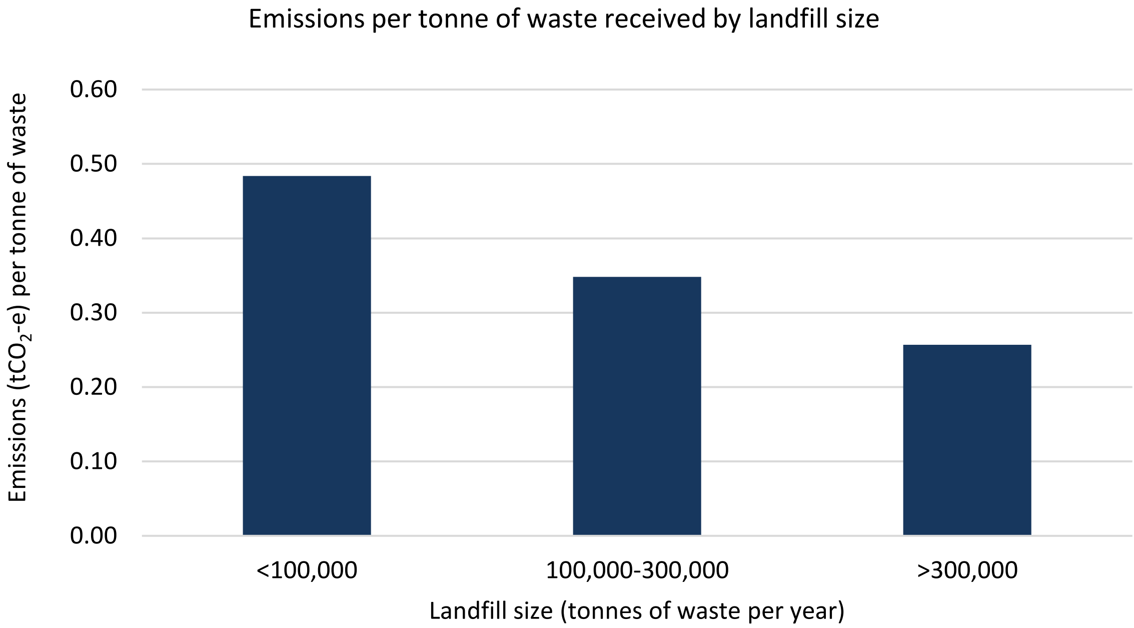

Figure 18: Emissions per tonne of waste received by landfill size

Using this data, the GHG emissions per tonne of waste was categorised by State. This shows that Western Australia has the largest emissions per tonne received, whilst Victoria has the lowest (see Figure 19).

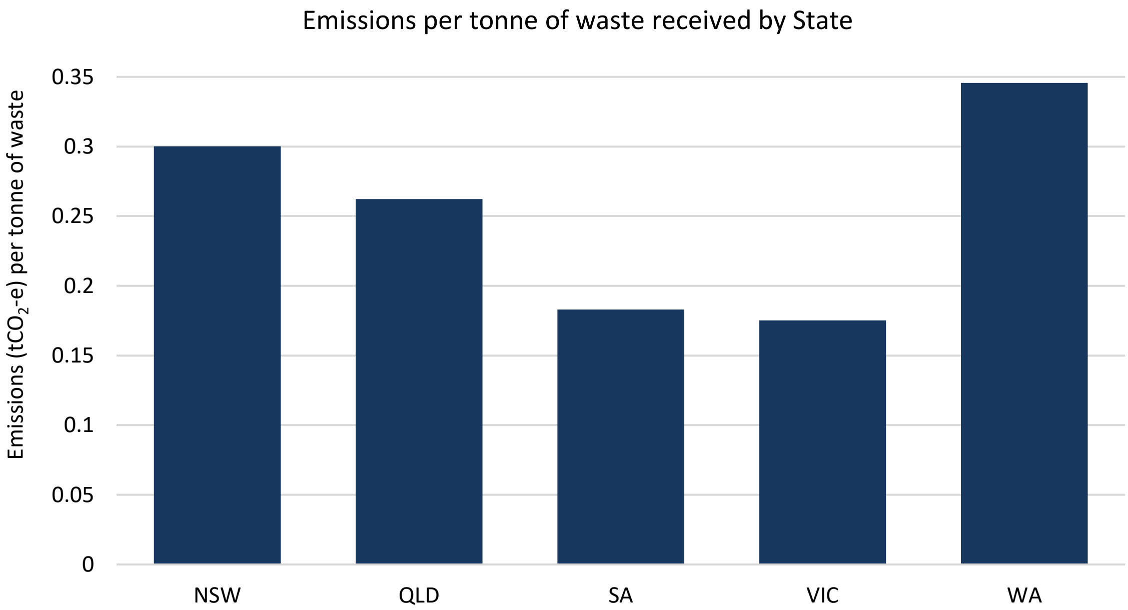

Figure 19: Emissions per tonne of waste received by State

The data obtained for the 22 sites where waste received tonnes were determined is provided in Table 19.

Table 19: Landfills by name and location with tonnage and emissions data

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Conclusion 33 The data obtained shows a trend that bigger landfills have higher emissions which would be expected. However bigger landfills also tend to capture more of the landfill gas so the emissions per tonne of waste received is in general lower for larger landfills.

Conclusion 34 Data on landfill tonnes per annum can be very difficult to obtain in the public domain. For some landfills, it was possible to obtain this data from literature searches, however whilst all sites were searched for it is apparent that this information is not readily available. It is therefore recommended that the state and federal Governments try to collate this information together so it is more available.

Conclusion 35 Scope 1 GHG emissions data for landfills provided by the CER highlights some issues in this data collection and quality. For instance, there are a significant number of facilities that have only reported for one year, not all years, or have stopped reporting altogether. There could be valid reasons for this such as being below a reporting threshold, change of name, data missing, etc. however it would be expected that landfills should have relatively consistent emissions profiles year on year so some further investigation into the scope 1 emissions reported under NGER or State Governments should be undertaken.

Conclusion 36 For ERF projects the waste received at a landfill (split by waste type / composition) is required for calculated abatement. It would be useful if the CER or DoEE collated this information so further analysis can be performed of different landfill characteristics.

6.1.2 Whether or not the landfill has one or more gas capture systems, and mode of landfill gas destruction (whether flare, combustion engine, boiler or other device)

Data obtained from the CER included landfill gas captured for some facilities. It was noted that several landfills that were known to capture landfill gas did not have data on the total methane captured. This maybe because:

- State Governments do not collect this information;
- due to reporting thresholds; or
- how the data is managed.

The initial focus of the analysis of gas capture was therefore on those sites which were included in the data obtained. To analyse gas capture rates, the following steps were taken:

1. Landfill facility data was filtered to only include sites where landfill gas capture data was included.
2. The data was manipulated to merge any sites which were reported under more than one year.
3. The data was combined with the GHG emissions data to give the capture rates for different landfill facilities.

4. The volume of landfill gas flared data was very limited. Only a few sites had this data for more than one year. Therefore, this data was not further assessed.

5. Average landfill gas capture rates were determined and compared to other data sets including the ERF project registry.

From the CER data, there were 34 landfill facilities with total methane captured data. Combining this data with GHG emissions data and tonnes of waste received produced results as summarised in Table 20.

For the 34 landfill facilities, it was possible to determine the tonnes of waste received for 15 sites, 13 have closed, and tonnage was unknown for the remaining 6 locations. Of the 34 sites with gas capture data, 18 were registered with ERF projects, the remaining 16 were labelled as *unknown*. It is noted that these unknown sites could have projects but the names of the landfill do not match the ERF project name. Four (4) of the landfills have two (2) ERF projects (i.e. Eastern Creek Landfill, Lucas Heights, Woodlawn Bioreactor, and the Ti Tree Bioreactor). As such, a total of 38 projects were considered.

With regards to the type of combustion device at each location, it was possible to derive if it is 'flare only' from the ERF register. It was also possible to ascertain if the site has an engine through analysis of the REC registry (see section 6.1.3). Figure 20 summarises the analyse of the 38 combustion devices where DoEE have provided capture data.

Table 20: Landfill sites with gas capture data and other facility information

[redacted]

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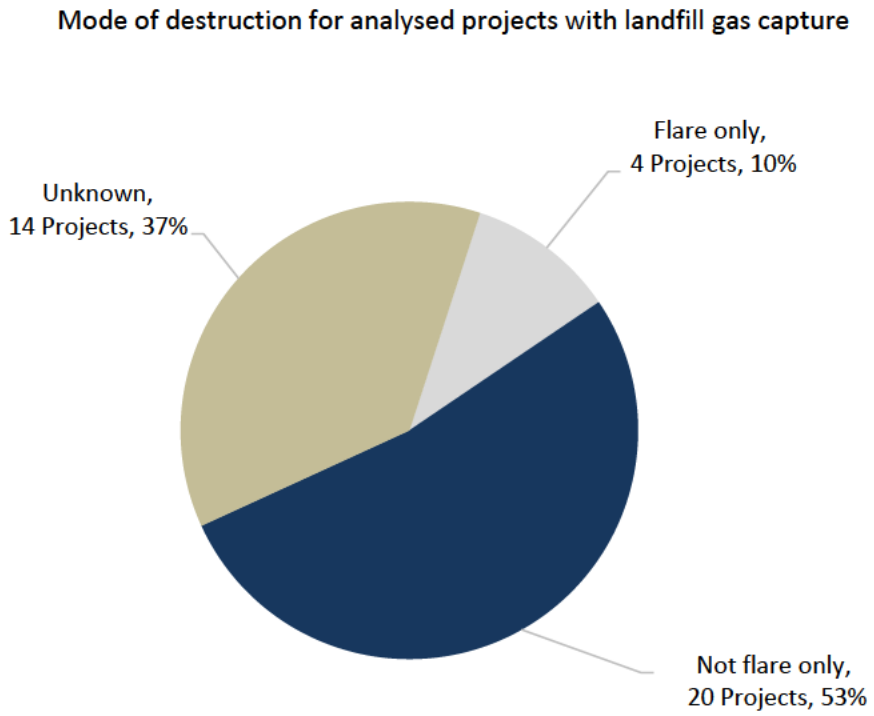

Figure 20: Analysis of the mode of destruction for 38 projects with landfill gas capture data

The following is noted:

- 14 of the projects were categorised as '*unknown*' because it was not possible to match them to either the REC or the ERF registers.
- 17 of the projects listed as '*not flare only*', were matched to the REC registry and it was concluded that they would have a combustion engine.

It could be considered that almost all the '*not flare only*' projects have internal combustion engines (i.e. rather than boilers) as:

- finding a heat use at a landfill site could be difficult; and
- the financial driver of electricity generation is in general the most economic use of landfill gas.

There were some anomalies in the data provided by the DoEE that warranted additional investigation. Firstly, there were several sites that were known to either have RECs or be registered as an ERF project, therefore it is not clear why no capture data was available for these sites. To assess those sites that were registered ERF projects a review of the ERF project register was conducted. Table 21 summarises the sites that did not have landfill gas capture data but were identified as ERF projects.

Table 21: Landfill sites without landfill gas capture data but identified as ERF projects

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[redacted]

There are 102 projects on the ERF register, of these 18 were identified as included in the DoEE data for landfill gas capture. A further 14 were identified has having emissions data but not gas capture data. There were also 4 landfills that had two ERF projects on the same landfill. This gives a total of 36 ERF projects that could be matched to the emissions and gas capture data provided by the DoEE. It is possible that more landfills are included but that they do not have more than one year of emissions data or could not be identified using the ERF project name. This does leave a significant amount of ERF projects that do not appear to have good quality data for emissions or gas capture collected by the DoEE. A likely reason for this is that they are below reporting thresholds for NGER, or that the ERF project has a different name to the landfill. There are also several ERF projects that have not yet generated any ACCUs.

For the landfills with landfill gas capture data further analysis was undertaken. Firstly, an assessment of the correlation between gas capture rate (%) and landfill size was conducted. This analysis excluded those sites that were closed or the tonnages were unknown, so a total of 15 landfills were included in the sample. The gas capture rate was determined by taking the average for each year where data was available. Figure 21 shows a scatter plot comparing landfill size with the gas capture rate.

Average gas capture ratio compared to tonnes of waste received p.a.

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Figure 21: Average gas capture rate (%) for different landfill sizes (tonnes of waste received per year)

It is noted that it was not possible to validate the data quality of the information provided by the CER. For example, some outliers were included, there are missing years of data. A key assumption was made; that the gas capture rate is determined by dividing "total gas captured" by "total emissions" (i.e. landfill emissions plus gas captured). If the data was available, further analysis could be performed on the age of the landfill, emissions rates, and capture rates for open and closed landfills. Further assessment is not possible based on the data available.

6.1.2.1 ERF register and ACCU data

An assessment was performed of the ERF register to assess the ACCUs generated by different projects. The available ACCU data has some limitations (e.g. the reporting period covered is not known). ACCUs are issued following the approval of an offsets report and all projects have different dates and reporting periods. Nonetheless, it is possible to derive useful information of relevance to this assessment.

Firstly, of the 102 ERF projects, it is apparent that 86 project have generated ACCUs. A total of 13.2m ACCUs have been issued over the period from 2012/13 to 2016/17. This gives an average of over 150,000 ACCUs per project, which equates to over 30,000 ACCUs per project per year. It is noted that this data set is likely to have inaccuracies as not all projects commenced in 2012/13 and not all ACCUs up to the current date have been issued. Alternatively, if it is assumed that the average project length to date is 3 years (i.e. not 5 years) then, the average per project would be 50,000 ACCUs per year.

If it is assumed that all projects have a 30% baseline and other project emissions are not material, then the total gas captured (gross abatement) is on average just over 70 ktCO_2-e per annum. Comparing this to the DoEE data the average gas capture over the period between 2012/13 to 2015/16 is over 150 ktCO_2-e per annum. The difference is likely to be explained by smaller landfills that do not report under NGER and hence would give a lower average gas capture rate.

6.1.3 Whether the landfill is generating credits under the Renewable Energy Target or exporting electricity generated from the combustion of landfill gas

Details of landfill gas projects that are generating credits under the RET can be derived from the REC registry, available at: https://www.rec-registry.gov.au/rec-registry/app/home

The registry was reviewed and all landfill gas projects were extracted into a database. Each of these was matched to an ERF project if possible. There were a total of 66 projects included in the REC registry, of these it was possible to match 41 to ERF projects. For the remainder of 25 it is possible these are also ERF projects under a different name. It is anticipated that as all 66 projects are generating credits under the Renewable Energy Target, then these are also exporting electricity generated from the combustion of landfill gas. No further data was available for analysis. Table 22 summarises the project data from REC registry matched to the ERF register.

Table 22: REC Registry landfill gas projects

State	Name	Company	ERF Project
ACT	Belconnen LFG Power Plant	EDL LFG (ACT) Pty Ltd	Yes
ACT	Mugga Lane LFG Power Plant	EDL LFG (ACT) Pty Ltd	Yes
NSW	AGLSITA1– LFG - NSW	AGL Energy Services Pty Limited	Unknown
NSW	Kincumber LFG - NSW	AGL Energy Services Pty Limited	Yes
NSW	West Nowra Landfill Gas	AGL Energy Services Pty Limited	Yes
NSW	Woy Woy LFG - NSW	AGL Energy Services Pty Limited	Yes
NSW	Belrose LFG Power Plant	EDL LFG (NSW) Pty Ltd	Yes
NSW	Eastern Creek LFG Power Plant	EDL LFG (NSW) Pty Ltd	Yes
NSW	Grange Avenue Power Station	EDL LFG (NSW) Pty Ltd	Yes
NSW	Jacks Gully	EDL LFG (NSW) Pty Ltd	Yes
NSW	Lucas Heights I & II LFG Power Plant	EDL LFG (NSW) Pty Ltd	Yes
NSW	Albury LFG - NSW	LMS Energy Pty Ltd	Yes
NSW	Awaba - LFG - NSW	LMS Energy Pty Ltd	Yes
NSW	Buttonderry LFG - NSW	LMS Energy Pty Ltd	Yes
NSW	Eastern Creek 2 LFG - NSW	LMS Energy Pty Ltd	Yes
NSW	Stotts Creek - Landfill Gas (LFG) - NSW	LMS Energy Pty Ltd	Unknown
NSW	Summer Hill (Wallsend) LFG - NSW	LMS Energy Pty Ltd	Yes
NSW	Macarthur Resource Recovery Park - Biomass based components of MSW-NSW	SITA Australia Pty Ltd	Unknown
NSW	Woodlawn Bioreactor LFG - NSW	Woodlawn Bioreactor Energy Pty Ltd	Yes
NT	Shoal Bay LFG - NT	LMS Energy Pty Ltd	Yes
QLD	Browns Plains LFG Power Plant	EDL LFG (Qld) Pty Ltd	Yes
QLD	Roghan Road LFG	EDL LFG (Qld) Pty Ltd	Yes
QLD	Sleeman Sports Centre LFG QLD	Energy Impact Pty Ltd	Unknown
QLD	Dakabin LFG-QLD	Landfill Gas Industries P/L	Unknown
QLD	Gladstone LFG-QLD	Landfill Gas Industries P/L	Yes
QLD	Maryborough LFG-QLD	Landfill Gas Industries P/L	Yes
QLD	Willawong - LFG - QLD	Landfill Gas Industries P/L	Yes
QLD	Birkdale LFG - QLD	LMS Energy Pty Ltd	Yes

State	Name	Company	ERF Project
QLD	Molendinar Landfill	LMS Energy Pty Ltd	Yes
QLD	Reedy Creek	LMS Energy Pty Ltd	Yes
QLD	Rochedale LFG	LMS Energy Pty Ltd	Yes
QLD	Stapylton LFG	LMS Energy Pty Ltd	Yes
QLD	Suntown Landfill Power Station	LMS Energy Pty Ltd	Yes
QLD	Swanbank Renewable Energy - LFG - QLD	LMS Energy Pty Ltd	Yes
QLD	Whitwood Road LFG	LMS Energy Pty Ltd	Unknown
QLD	Swanbank	Stanwell Corporation Limited	Unknown
QLD	Ti Tree LFG Willowbank - QLD	Veolia Environmental Services (Australia) Pty Ltd	Yes
SA	Pedler Creek LFG Power Plant	EDL LFG (SA) Pty Ltd	Yes
SA	Wingfield I & II LFG Power Plant	EDL LFG (SA) Pty Ltd	Unknown
SA	Highbury LFG Power Plant	EDL Operations (Highbury) Pty Ltd	Unknown
SA	Tea Tree Gully LFG Power Plant	EDL Operations (Tea Tree Gully) Pty Ltd	Unknown
TAS	Glenorchy LFG - TAS	AGL Energy Services Pty Limited	Yes
TAS	McRobies Road - Landfill Gas (LFG) - Hobart - TAS	AGL Energy Services Pty Limited	Yes
TAS	Mowbray - LFG - TAS	LMS Energy Pty Ltd	Unknown
VIC	Berwick LFG Power Plant	EDL LFG (Vic) Pty Ltd	Unknown
VIC	Broadmeadows LFG Power Plant	EDL LFG (Vic) Pty Ltd	Unknown
VIC	Brooklyn LFG Power Plant	EDL LFG (Vic) Pty Ltd	Yes
VIC	Corio LFG Power Plant	EDL LFG (Vic) Pty Ltd	Unknown
VIC	Springvale & Clayton LFG Power Plant	EDL LFG (Vic) Pty Ltd	Unknown
VIC	Transpacific LFG - Truganina VIC	Landfill Operations Pty Ltd	Yes
VIC	Cosgrove LFG - Vic	LMS Energy Pty Ltd	Unknown
VIC	Eaglehawk - LFG - VIC	LMS Energy Pty Ltd	Unknown
VIC	Hampton Park - LFG - VIC	LMS Energy Pty Ltd	Unknown
VIC	Mornington Landfill	LMS Energy Pty Ltd	Yes
VIC	Smythesdale LFG - VIC	LMS Energy Pty Ltd	Unknown
VIC	Wollert-Landfill Gas (LFG)-VIC	LMS Energy Pty Ltd	Yes
VIC	Wyndham Landfill	LMS Energy Pty Ltd	Yes
WA	Kelvin Road LFG	AGL Energy Services Pty Limited	Yes
WA	Millars Road LFG	AGL Energy Services Pty Limited	Yes
WA	Canningvale	LANDFILL GAS and POWER PTY. LTD.	Unknown
WA	Kalamunda Power Station	LANDFILL GAS and POWER PTY. LTD.	Unknown
WA	Red Hill Power Station	LANDFILL GAS and POWER PTY. LTD.	Unknown
WA	Tamala Park	LANDFILL GAS and POWER PTY. LTD.	Unknown
WA	Atlas WA LFG	LMS Energy Pty Ltd	Unknown
WA	South Cardup WA LFG	LMS Energy Pty Ltd	Yes
WA	Henderson/Wattleup Landfill Gas (LFG) - WA	Waste Gas Resources Pty Ltd	Unknown

6.2 Assessment, including reasoning, of the maximum percentage of landfill gas which can realistically be captured on a landfill site during operation and after the cell is capped. This must include an examination of the factors that influence the level of gas capture, including responses to the following questions:

__Summary:__

Key factors affecting the proportion of maximum possible gas collection are depth, width, type of waste, leachate issues, how hot the climate is, how wet the climate is, type of cap, type of lining, how well the landfill is managed is general.

The NGER Measurement Determination assumes that a maximum 75% of gas generated can be collected; actual practice anecdotally and from literature varies from zero (no collection) to under 50% for poorly managed sites to nearly 100% at sites with the most effective collection management.

Note that the percentage of gas collection is not a factor considered in the 2012 or 2015 Methods; crediting is on the basis of tons of methane above the baseline amount oxidised.

6.2.1 Does the size of a landfill affect how much gas can be captured? If so, how?

6.2.1.1 Landfill Size

Anecdotally, larger tonnage landfills tend to collect a higher portion of landfill gas. This is partly because smaller landfills may lack the economy of scale to make efficient gas collection, or indeed any gas collection, economically feasible.

For a given tonnage size, landfill physical size theoretically has a small negative impact on gas collection. This is, a physically larger but identical tonnage landfill will have a higher collection line installation cost and annual maintenance cost. This is due to the larger distances for the physically larger site.

6.2.2 What other factors influence the maximum proportion (compared to total landfill gas produced) of gas capture at a site?

Other key factors affecting the proportion of maximum possible gas collection are:

- The time since waste was deposited,
- Cell design,
- Type of waste,
- Leachate issues,
- Weather conditions how hot the climate is, how wet the climate is,
- Landfill management.

These factors are described in the below sections.

6.2.2.1 Time since waste is deposited

Immediately after waste deposition, gas generation is low and collection will be difficult and expensive per tonne. Typically, gas wells are installed when a cell is complete; collection lines are drilled vertically into the finalised waste body, so all (100%) of gas generation before that time will be lost to atmosphere. After several years of strong gas generation and collection, gas generation volumetric rate and methane concentration will decline to the point that capture is no longer economically or operationally feasible, and collection percentage will decline and then become zero when collection ceases.

6.2.2.2 Cell design and landfill management

The largest source of gas leakage into atmosphere avoiding collection pipework and possibly avoiding oxidation in the landfill cap is generally thought to occur at the boundaries between cells. In most cases cells 'lean' on each other, and the boundary, prior to filling of the subsequent cell, is intermediate cover. There is an easy (i.e. low pressure drop and high volume) path that gas can take straight to atmosphere, so the percentage of generated gas collected will be lower. The degree to which this happens depends on the landfill design (including depth, width, type of cap, type of lining, etc.), construction and operation over time.

The quality of sealing around penetrations also affects the percentage of gas not collected because of leakage at the penetration. Penetrations include leachate sumps, leachate monitoring bores and gas bores for collection pipelines.

When landfills or cells are deep, horizontal layers of pipes connected to risers may be installed. This avoids some of the leakage discussed above. The Woodlawn site at Tarago, NSW is an example of a site using this technique.

The type of cap installed will also have an effect on the potential gas collection, for example:

- A clay cap can funnel emissions to cracks, allowing greater loss to atmosphere with low levels of oxidation.
- A thick and more permeable layer, such as a phytocap, allows slow leakage, so there is less chance of cracks, slower percolation of gas through the cap and more oxidation. High levels of organic matter in the cap increases oxidation because it provides more sites for the methanogenic bacteria to work. Research based on the relative levels of C12 and C13 components in the gas stream shows the potential for oxidation rates of 40% and more[56,57].

For a completed landfill cell, most of the uncaptured gas probably exits through cracks or edges of penetrations. That means the proportion of capture is significantly dependent on the degree of monitoring (to find the leaks) and maintenance (to fix them). The maximum theoretical capture rate is high if the operator actively manages the landfill gas. The operator of the landfill gas collection equipment may not be the party determining that level of attention and expenditure.

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[56] Yoojin Jung, Paul T. Imhoff, Don C. Augenstein, and Ramin Yazdani (2009), Influence of high-permeability layers for enhancing landfill gas capture and reducing fugitive methane emissions from landfills.

[57] K. Spokas, J. Bogner, J.P. Chanton, M. Morcet, C. Aran, C. Graff, Y. Moreau-Le Golvan and I. Hebe (2005) Methane mass balance at three landfill sites: What is the efficiency of capture by gas collection systems? in Di Maria, F., Sordi, A. and Micale, C., (2013) Experimental and life cycle assessment analysis of gas emission from mechanically–biologically pretreated waste in a landfill with energy recovery. Waste Management, 33(11), pp.2557-2567

6.2.2.3 Type of waste, ambient conditions

The velocity of gas generation will depend on the type of waste (i.e. percentage of the waste that is putrescible) and ambient conditions (i.e. hotter and wetter conditions create more rapid degradation and gas generation). More rapid generation would lead to earlier economically feasible installation of collection lines.

6.2.2.4 Leachate

Higher leachate flow, meaning more putrescible material leaking from the cell with leachate water, will decrease the percentage of landfill gas collection. This is because the leachate degrades and ejects gas directly to atmosphere. Unless handled in a facility where the off gas is directed to the gas destruction equipment.

6.2.2.5 Landfill gas collection efficiency

Despite the widespread use of landfill gas collection systems in many parts of the world for over three decades with approximately 955 (as of 2007) landfills collecting landfill gas worldwide[58], little information on their capture efficiency is available[59]. Such an understanding would result in more rationally designed landfill gas collection systems that might improve methane capture efficiency.

Whilst landfill gas collection rates are readily and accurately measured in the ERF landfill gas methodologies, the landfill gas generation rates (the second measurement needed for determining efficiency), are usually unknown or have a high degree of uncertainty.

Several methods have been proposed to estimate the landfill gas generation rate at a landfill, amongst them are:

- combining pneumatic well test data with assumptions about well recovery to estimate landfill gas generation[60];
- employing biokinetic models describing stages of waste decomposition[61];
- using simple first-order kinetic gas generation models such as the *Landfill Gas Emission Model* (LandGEM)[62] and the CLEEN Model[63] by Karanjekar et al (2015). This last achieves a regression R^2 value of 0.75 for a first-order methane generation rate constant value k as a function of waste composition, annual rainfall, and temperature.

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[58] Nickolas J. Themelis and Priscilla A. Ulloa (2007) Methane generation in landfills, Renewable Energy 32, p.1244.
[59] Jung, Y., Imhoff, P. and Finsterle, S. (2011) Estimation of landfill gas generation rate and gas permeability field of refuse using inverse modelling, Transp Porous Med 90, pp. 41–58.
[60] Emcon, A. (1980) Methane generation and recovery from landfills. Ann Arbor Science, AnnArbor, MI, USA.
[61] El-Fadel, M., Findikakis, A.N. and Leckie, J.O., (1996) Numerical modelling of generation and transport of gas and heat in landfills I. Model formulation. Waste management & research, 14(5), pp.483-504..
[62] USEPA (2005) Landfill Gas Emissions Model (LandGEM). Accessed 18 Aug 2017. Available from: https://www.epa.gov/catc/clean-air-technology-center-products#software
[63] Karanjekar, R.V., Bhatt, A., Altouqui, S., Jangikhatoonabad, N., Durai, V., Sattler, M.L., Hossain, M.S. and Chen, V., (2015) Estimating methane emissions from landfills based on rainfall, ambient temperature, and waste composition: the CLEEN model. Waste Management, 46, pp.389-398.

However, these methods suffer from significant limitations. Estimates based on pneumatic well tests rely on precise pressure measurements[64,65]. Biokinetic modelling requires biokinetic parameters and detailed data about the refuse, such as mass fractions for each waste category that are often unavailable or estimated with limited data[66]. Kinetic models also require parameters that must be estimated. These methods therefore provide only limited information or quantitative understanding.

The NGER Measurement Determination section on landfill gas uses a first order decay method to estimate methane generation. The NGER model that determines gas production from a landfill is a model known to over and under estimate actual gas production. In one anecdotal case, gas collection was more than double that modelled.

Because the quantitative estimation of landfill gas generation is challenged, trying to determine a maximum gas capture proportion for operational landfills is also challenging, and quoted recovery percentages vary widely.

A Life Cycle Analysis (LCA) study undertaken for the European Community found an average gas recovery rate in the European Union (EU) of 33%. This recovery rate was estimated based on the proportion of waste thought to be sent to landfills having gas recovery, country-specific estimates of operational gas recovery rates and an estimated proportion of emissions that occur before or after gas recovery systems are installed[67]. The study noted, however, that operational gas recovery of 70% to 90% of the methane is achievable, and undertook sensitivity analysis on higher rates.

A paper[68] on the impact of landfill on GHG emissions found literature that states a range of landfill gas collection efficiency, such as:

- Pipatti and Wihersaari[69] stated efficiencies between 50% and 100%;
- Oonk and Boom[70] between 24% to 60%; and
- Humer and Lechner[71] between 40% to 60% efficiency.

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[64] Pierce, J., LaFountain, L. and Huitric, R., (2005) Landfill gas generation & modeling manual of practice. Solid Waste Association of North America.
[65] Walter, G.R., (2003) Fatal flaws in measuring landfill gas generation rates by empirical well testing. Journal of the Air & Waste Management Association, 53(4), pp.461-468.
[66] El-Fadel, M., Findikakis, A.N. and Leckie, J.O., (1997) Gas simulation models for solid waste landfills. Critical reviews in environmental science and technology, 27(3), pp.237-283.
[67] Smith, A., Brown, K., Ogilvie, S., Rushton, K. and Bates, J., (2001) Waste management options and climate change: Final report to the European Commission. In Waste management options and climate change: final report to the European Commission. European Commission.
[68] Lou, X.F. and Nair, J., (2009) The impact of landfilling and composting on greenhouse gas emissions–a review. Bioresource technology, 100(16), pp.3792-3798.
[69] Pipatti, R. and Wihersaari, M., (1997) Cost-effectiveness of alternative strategies in mitigating the greenhouse impact of waste management in three communities of different size. Mitigation and Adaptation Strategies for Global Change, 2(4), pp.337-358.
[70] Oonk, H. and Boom, T., (1995) Validation of landfill gas formation models. Studies in Environmental Science, 65, pp.597-602.
[71] Humer, M. and Lechner, P., (1999) Alternative approach to the elimination of greenhouse gases from old landfills. Waste Management and Research, 17(6), pp.443-452.

Furthermore, the paper states that laboratory experiments by Bogner and Spokas[72] yielded values ranging 25–50%. This range of recovery efficiency is largely dependent on the waste composition and moisture content. Waste streams with a low organic fraction, e.g. food waste, will result in lower capture efficiency, which others with a higher degradable organic carbon (DOC) such as paper or waste sludge are able to achieve higher capture efficiencies due to the amount of biogas produced[73]).

Knowing the efficiency of biogas capture can have great implications for the GHG mitigation potential. This is illustrated by a study in Phuket, Thailand, where a 50% recovery of landfill gas was recorded which led to a GWP reduction around 58% of the total landfill's GWP[74].

In this context, the maximum collection rate assumed in the NGER Measurement Determination of 75% seems a reasonable value for the practical maximum gas collection percentage. It is worth noting that the Methodology credits for actual, metered destruction above a baseline, as opposed to percentage of collection.

Conclusion 37 Key factors affecting the proportion of maximum possible gas collection are depth, width, type of waste, leachate issues, how hot the climate is, how wet the climate is, type of cap, type of lining, and how well the landfill is managed in general.
The NGER Measurement Determination assumes that a maximum 75% of gas generated can be collected; actual practice anecdotally and from literature varies from zero (no collection) to under 50% for poorly managed sites to over 95% at sites with the most effective collection management.
Note that the percentage of gas collection is not a factor considered in the 2012 or 2015 Methodologies; crediting is on the basis of tons of methane oxidised above the baseline proportion.

6.3 Costs of installing and maintaining a landfill gas capture and flare system, including a breakdown of capital costs, installation costs and all ongoing costs.

A high level indicative CAPEX and OPEX assessment for a landfill gas system was performed. The system considered the landfill gas capture, flaring and power generation components. It is noted that landfill sites with power generation capacity will normally have both systems. This is because the excess landfill gas will be flared, whilst using the electricity system at its maximum capacity, or to flare the gas when the engines are unavailable. The below estimates are for indicative comparison and high level uses only. The estimates are based on market research and statistical data from previous projects.

The costs exclude landfill activities (e.g. land purchase, landfill equipment and buildings, fencing, approvals, site or cell development, operations, capping, rehabilitation and aftercare). The costs also exclude the electrical transmission, distribution and associated infrastructure.

[72] Bogner, J. and Spokas, K., (1995) Carbon storage in landfills. Soils and Global Exchange, edited by R. Lai, et al, pp.67-80.
[73] See for example DCC (Department of Climate Change), 2008. National Greenhouse Accounts Factors. http://www.greenhouse.gov.au/workbook/index.html accessed 25 July 2008.
[74] Liamsanguan, C. and Gheewala, S.H., (2008) The holistic impact of integrated solid waste management on greenhouse gas emissions in Phuket. Journal of Cleaner Production, 16(17), pp.1865-1871.

Furthermore, electrical connection costs (which are required to export electricity to the grid) are a considerable cost. Nevertheless, these costs:

- are site specific; and
- based on the grid infrastructure available in the region / area, the network operator determines the costs associated with the connection.

As such, only the capturing, flaring and power generation system has been considered. Key considerations are summarised in Table 23. Furthermore, Table 24 and Table 25 provide a breakdown of the CAPEX and OPEX estimates respectively. The breakdown of these costs is graphically presented in Figure 22 and Figure 23.

Table 23: Key considerations for CAPEX / OPEX estimates

Consideration	Metric	Qty.	Unit
Landfill gas production	Operating Temperature	25	°C
	Operating Pressure	5	bar
	Gas flow at Standard conditions	988	Sm^3/hr
	Gas flow at Normal conditions	905[75]	Nm^3/hr
Equivalent of waste	Estimate that 80% is MSW waste	1,018,221	Tonnes/year
	Assumed density	170[76]	Sm^3/tonne of waste
Size of landfill	Area	101,822	m^2
	Depth (estimated)	10[77]	m
Potential equivalent of electrical generation		1.78	MWe

[75] This estimate has been primarily based on available gas flow as the key indicator for the calculations.
[76] High level estimate to determine the approximate size (i.e. volume) of landfill required (based on amount of gas flow).
[77] Assumed that the depth of the landfill cell to be 10m for estimation purposes only.

Table 24: Estimated CAPEX costs of installing a landfill gas capture, flare and power generation system

No.	Items	Description	Assumptions	Units	Indicator	Units 2	Nos.	Total AUD[78]
1	CAPEX Cost							$ 4,233,370
1.1	Landfill gas capturing system							$ 599,000
1.1.1	*Wellheads*	*Well system to extract methane beneath landfill cell*	*Each wellhead system covers 60m by 60m area with a depth of 5-10m*	*$/ wellhead*	*$ 2,500*	*Number of wellheads*	*28[79]*	*$ 71,000*
1.1.2	*Gas capture piping headers*	*Piping for capture of gas*	*Piping to connect wellheads to flare system. Assumed pipelines crossed the length twice in total.*	*$ per m*	*$ 600*	*m*	*700[80]*	*$ 420,000*
1.1.3	*Additional Equipment*	*Associated equipment for the landfill gas capturing system (pumps, blowers, etc.)*	*Assumed 15 % of equipment cost*	*%*	*15%*	*%*	*15%*	*$ 108,000*
1.2	Flare System[81]	Flaring methane gas	Assumed USD$200 (AUD$250) per Nm^3/hr landfill gas	$	$ 250	Nm^3/hr LFG	905	$ 226,250
1.3	Electrical Controls	Associated electrical system for the gas capture and flare system	Assumed 10 % of equipment cost	%	10%	%	10%	$ 72,000
1.4	Power Generation	Utilising landfill gas to generate electricity through gas engines	Based on estimated 19 MJ/Sm^3 gross calorific value of landfill methane gas and 35% of gas engine efficiency	$ / kWe	$ 1,800	kWe	1,778[82]	$ 3,201,120
1.5	Engineering	Engineering costs	Includes gas capture, flaring and power generation	%	15%	%	15%[83]	$ 135,000

[78] The estimates are for indicative comparison and high level uses only. These figures are based on market research and statistical data from previous projects. This only includes gas gathering and power generation aspect, landfill capping/process is not included.
[79] Assumes a wellhead is installed for every 60m by 60m of landfill area.
[80] Estimated value, based on professional experience and scalability potential.
[81] Including biogas flare, piping, piping components, blowers, etc.
[82] The power generation component includes gas engines, biogas scrubbing system, gas/exhaust, pipework, associate electrical works (instrumentation and control, high voltage switchgear, switchboard, control systems, transformers, circuit breakers, etc.), general mechanical/civil/earth works.
[83] Engineering includes project management, civil/electrical/environment planning engineering, construction and commissioning supervision, develop cost and construction insurance.

Figure 22 provides a breakdown of the estimated capital expenditure required for the landfill gas capture, flaring and power generation system. Power generation system alone (1.78 MWe considered) represents 76% of the costs.

It is noted that for a landfill gas capture and flaring system, all the costs indicated in the graph (e.g. wellheads, gas capture piping headers, etc.) would be required. The cost breakdown for the gas capture and flare system has been included between brackets.

The gas piping headers represent 10% of the power generation system cost and 41% of the gas capture and flare system. The flare system represents 5% of the power system cost and 22% of the gas capture and flare system.

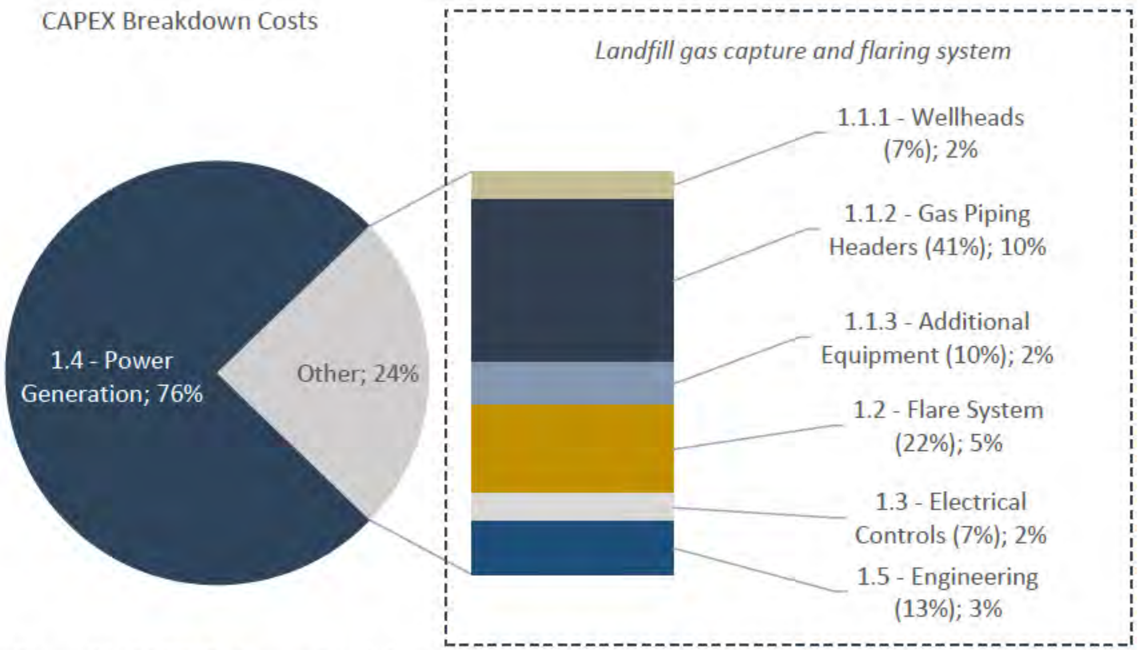

Figure 22: CAPEX Estimates Breakdown – Landfill gas capture, flaring and power generation

The gas piping headers and collection lines costs will dependent on the area of the landfill. This is, the distance to the cell being drained and the depth of the cell[84]. Other costs are:

- Engineering costs, which represent 3% of the power generation system cost and ~10% for the gas capture and flare system (it is noted that the graph shows 13% as it considers other activities).
- Additional equipment (e.g. pumps) represents 2% of the power generation system and 10% of the gas capture and flare system.
- The wellheads and electrical controls each represent 2% of the power generation system and 7% of the costs of the gas capture and flare system.

[84] The gas piping costs are highly variable due to the geometry of the landfill. Also, these factors will influence the gas flow. This is because the product of the area of the landfill times its depth will be approximately related to gas flow, with other variables being:

- the age (older filled cells will generate less volume per year), and
- percentage of waste that is putrescible (waste which is mainly construction waste will have a low gas volume per year).

Table 25: Estimated OPEX costs of maintaining and operating a landfill gas system

No.	Items	Descriptions	Assumptions	Units	Indicator	Units 2	Nos.	Total AUD[85]
2	OPEX Cost per annum							$ 353,150
2.1	Annual O&M of landfill gas capturing system	O&M for overall system	Assumed 10 % of capital cost p.a.	%	7%	%	10%[86]	$ 104,000
2.2	Potential extension of collection lines to new cell	Potential extension factors - wellheads and pipeline	Assumed 10% of wellheads p.a.	%	10%	%	10%[87]	$ 49,100
2.3	Annual O&M for power generation engines	Annual O&M for power generation engines	Assumed $10 per MWh and an availability factor of 90%	per MWh	$ 10	MWh	14,021	$ 140,210
2.4	Annual O&M of wellheads	O&M for the wellheads	Assumed 3 person-days per annum per well	per well	$ 600	no.	28	$ 17,000
2.5	Annual O&M of flare system	O&M for the Flare	Assumed 7% of the flare system CAPEX	%	7%	%	7%	$ 15,840
2.6	Insurance	Insurance for the plant	Assumed 0.5% of the capital cost p.a.	%	0.5%	%	0.5%	$ 22,000
2.7	General Administration	General administration	Assumed 2 person-days per month	daily rate	$ 200	days	24	$ 5,000
3	Engine overhaul		Estimate over the contract period (i.e. yr 1-7)					$ 1,835,480
3.1	Engine rebuild	After 5 to 6 years, the engine needs to undergo a complete refurbishment	Based on major services (overhaul) on the engines that need to be carried out every 16,000 MWh (year 3, 5, 7 and 9). A distributed unit cost is used for this estimate. Estimate based on 24/7 operation with 90% availability factor.	% of CAPEX	Year 3	%	7%	$ 224,100
3.2					Year 5	%	15%	$ 480,200
3.3					Year 7	%	12%	$ 384,200
3.4					Year 9	%	30%	$ 960,400[88]
3.4.1	*Year 9 consideration in contract period (i.e. the life of asset, considering years 1 to 7)*		*Assumed yearly costs are constant, no interest or inflation.*	*Year 9*	*(Years 1 to 7)*	*%*	*30%*	*$ 746,980*

[85] The high-level estimates are for indicative comparison purposes only. These figures are based on market research and statistical data from previous projects. This only includes the gas capture and power generation aspects only. Landfill capping/process is not included.

[86] The O&M cost does not include the landfill capping process. It only covers the gas capturing and flaring system.

[87] An estimate of potential extension of 10% per year was considered.

[88] Not considered in the OPEX Cost.

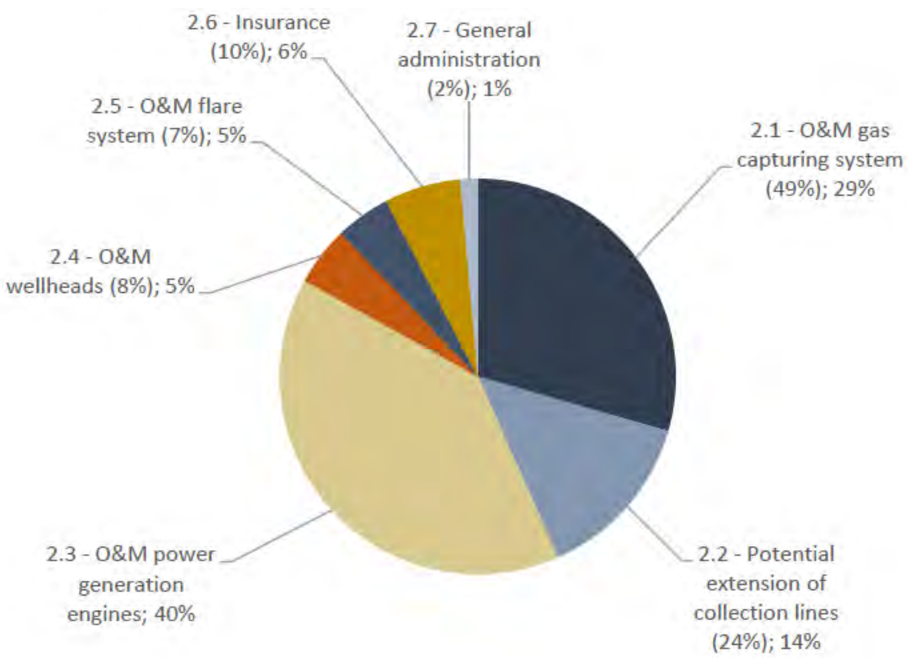

Figure 23: OPEX estimates breakdown - Landfill gas capture, flaring and power generation

Figure 23 provides a breakdown of the ongoing costs associated with a landfill gas capture, flaring and power generation system. The main cost is the operation and maintenance of the power generation engines with 40% of the costs. Other ongoing costs (applicable to both, the capture and flare and power generation systems) are:

- **Operation and maintenance of the gas capturing system, representing 29% of the of the power generation system and 49% of the gas capture and flaring system each;**
- **Potential continual extension of collection lines to new cells, representing 14% of the power generation system and 24% of the gas capture and flaring system;**
- **Insurance costs, representing 6% of the of the power generation system and 10% of the gas capture and flaring system;**
- **Operation and maintenance of the flare system and the wellheads, representing 5% of the of the power generation system each and 7% and 8% of the gas capture and flaring system respectively; and**
- **General administration which would account for approximately 1% and 2% of the ongoing costs.**

__Note:__
Engine rebuild (overhaul) costs (required after 3 years of operation) are not considered in the annual OPEX breakdown costs. They are considered separately as they are not a yearly expense and are provided overleaf.

Figure 24 provides a breakdown of the overhaul costs over the life of asset (i.e. years 1 to 7). These costs are:

- Year 3, corresponding to 7% of the CAPEX, and accounts for 12% of the overhaul costs over the life of asset;
- Year 5, corresponding to 15% of the CAPEX, and accounts for 26% of the overhaul costs over the life of asset;
- Year 7, corresponding to 12% of the CAPEX, and accounts for 12% of the overhaul costs over the life of asset; and
- The overhaul required on year 9, corresponds to 30% of the CAPEX. This expenditure falls out of the considered life of asset, nevertheless, and for representative purposes, the representative costs from year 1 to 7 have been considered. This accounts for 41% of the overhaul costs over the life of asset.

In total, these costs are expected to be AUD$1.84m. These costs are further considered in sections 6.3.1 and 6.3.2.

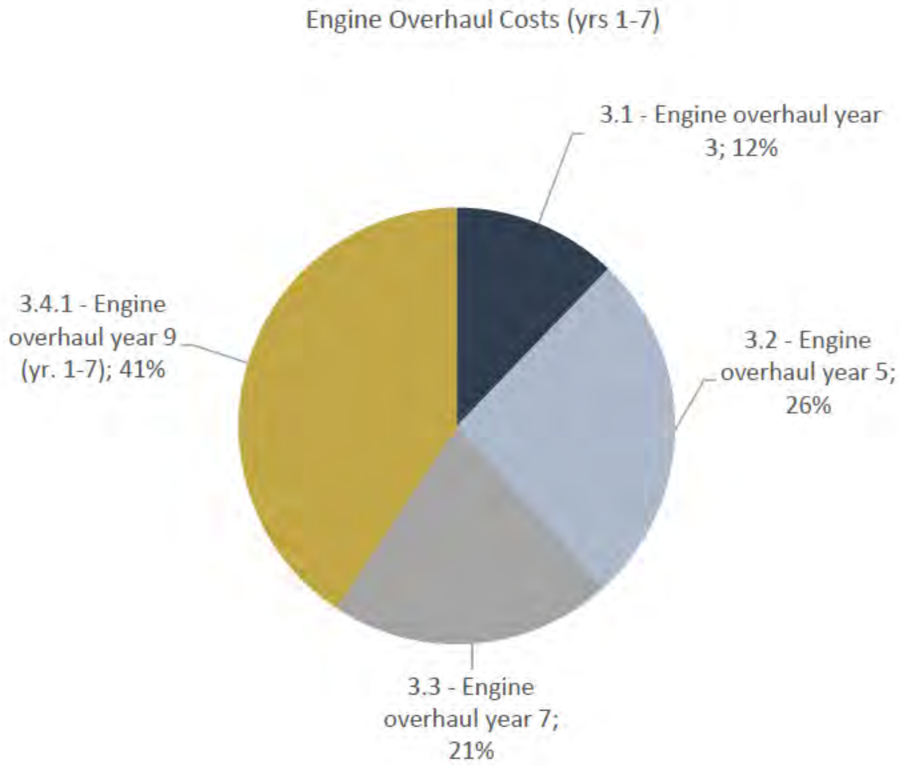

Figure 24: OPEX (engine overhaul) estimates breakdown

6.3.1 Regional Adjustment Consideration

To account for the geographical location variations in costs, a *Regional Adjustment* was determined. The *Regional Adjustment* is based on a building price index[89] and is provided for guidance purposes. The *Regional Adjustment* is provided in Table 26. Additionally, the CAPEX, OPEX and Overhaul costs for the capture, flaring and power generation of the different cities in Australia are provided. The estimates are based on the information provided in Table 24 and Table 25. Sydney costs were considered as the bases of this analysis (i.e. 100%).

Table 26: Regional areas adjustment estimates (AUD$ '000)

Region[90]	Sydney	Adelaide	Brisbane	Canberra	Darwin	Hobart	Melbourne	Perth
Regional Adjustment	**100%**	**88%**	**116%**	**89%**	**110%**	**83%**	**90%**	**108%**
CAPEX ('000)	$4,233	$3,728	$4,914	$3,769	$4,668	$3,501	$3,802	$4,583
OPEX ('000)	$353	$311	$410	$315	$390	$292	$318	$383
Overhaul ('000)	$1,835	$1,617	$2,131	$1,635	$2,024	$1,518	$1,649	$1,987

It is noted that the city of Hobart is the least expensive one and the most expensive one is Brisbane. Brisbane costs are 40% higher than Hobart costs. Pricing of construction costs is highly susceptible to geographical location.

6.3.2 Total Cost of Ownership Consideration

To consider the high-level estimations of the total cost of ownership, a seven-year's life of asset was considered. This timeframe was considered given the ERF's contract period.

For a landfill gas capture, flaring and power generation system as specified in section 6.3, it was estimated that the CAPEX required would total AUD$4.2m. To compare the ongoing costs associated with this system, the OPEX costs over the life of asset were considered. In total, OPEX (operation and maintenance of the system) costs were estimated to be AUD$2.5m. Furthermore, the power generation overhaul costs were considered and were estimated to be AUD$1.4m over the life of asset.

Conversely, similar costs were considered for a gas capture and flaring system only. For this system, the CAPEX was estimated to be AUD$1m and the OPEX over the life of asset AUD$1.5m. It is noted that no overhaul services are required for these systems.

These values are graphically presented in Figure 25. It is noted the total cost of ownership assessment did not consider any required rates of return and time value of money. This is because each project would have different required rates of return depending on their capital structure and risk appetite. However, it is expected that projects would require more than break even on an undiscounted cash flow assessment to be financially viable.

[89] Rawlinsons Quantity Surveyors and Construction Cost Consultants Australia (2016), Rawlinsons - Australian Construction Handbook Edition 34, Rawlinsons Publishing, Perth, WA, Australia, p3.
[90] Cities pricing adjustment is based on price indices for 2015 as indicated in Rawlinsons - Australian Construction Handbook Edition 34 for estimation purposes only.

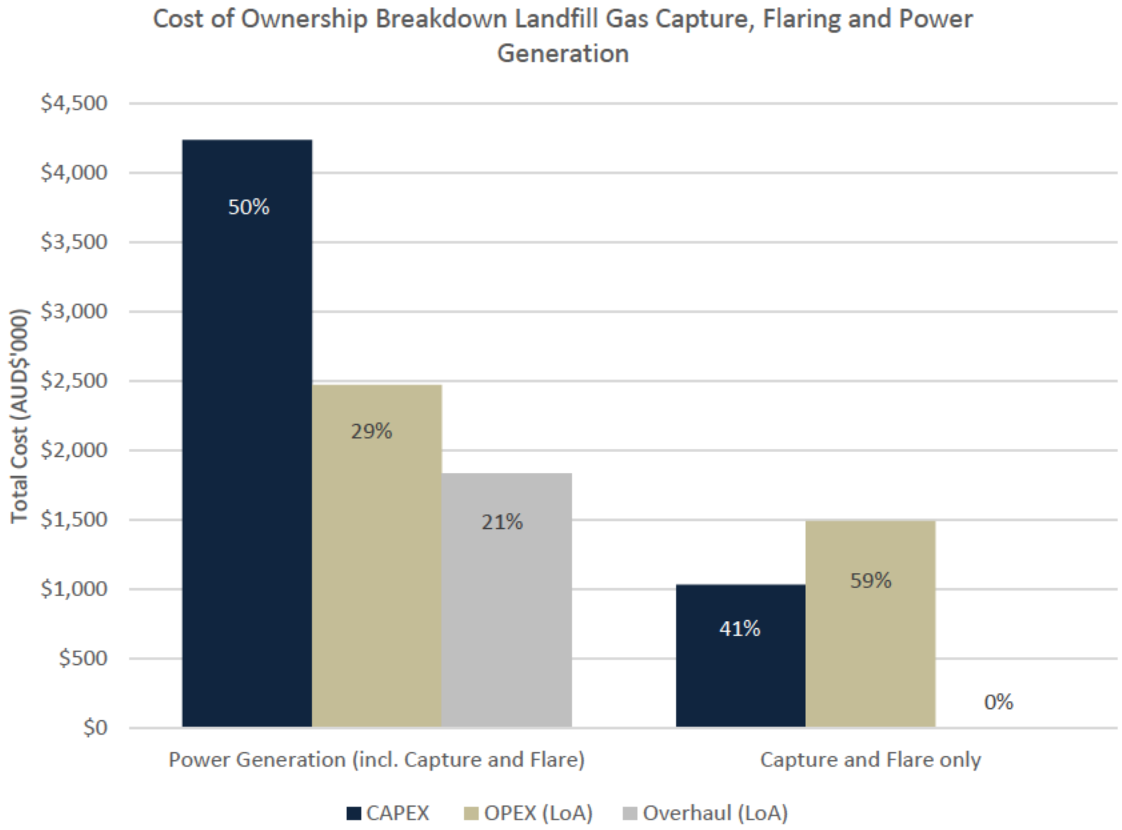

Figure 25: Total Cost of Ownership Breakdown (CAPEX and OPEX)

6.3.2.1 Consideration of electricity generation revenue and ACCUs

The energy generation revenue (i.e. electricity generation and LGCs) and the ACCUs were considered. These are based on estimates provided in section 2.3.2. Table 27 provides a high-level comparison between expenses incurred in a landfill gas power generation project and the potential revenue streams. Furthermore, Table 27 provides two scenarios; with and without ACCUs. In summary and considering the costs over the life of asset if a project:

- has the ACCUs-generating potential, the site will have revenue (approximately after five years of operation for a power generation project and four years for gas capture and flare); and
- does not have the potential to generate ACCUs, then:
  - the power generation project would not have reached parity between the expenses and income at the end of the life of asset; and
  - the gas capture and flare project will not have any income and will all represent costs.

Table 27: Total Cost of Ownership Balance[91]

Summary of expenses / income	Period	Power Generation		Capture & Flare	
		With ACCUs	No ACCUs	With ACCUs	No ACCUs
Total initial costs	One off	-$4,233,370	-$4,233,370	-$1,032,250	-$1,032,250
Total expenses p.a.	Annual	-$353,150	-$353,150	-$212,940	-$212,940
Total services overhaul (annualised)	Annual	-$261,922	-$261,922	$0	$0
Total income p.a.	Annual	$1,395,077	$841,260	$553,817	$0
Life of Asset (7 yr.)					
Total initial costs	One off	-$4,233,370	-$4,233,370	-$1,032,250	-$1,032,250
Total expenses over whole-of-life	LoA	-$2,472,050	-$2,472,050	-$1,490,580	-$1,490,580
Total services overhaul	LoA	-$1,833,450	-$1,833,450	$0	$0
Total income over whole-of-life	LoA	$9,765,550	$5,888,820	$3,876,720	$0
Total Cost of Ownership	**LoA[92]**	**$1,226,680**	**-$2,650,050**	**$1,353,890**	**-$2,522,830**

The following assumptions were made as part of this estimation:

- The total cost of ownership considers seven years of ACCUs, sale of electricity generated and LGCs, noting that they may not all be available from year one.
- The assessment does not consider revenue or levies from the handling or disposal of waste and excludes all costs of the operation of the landfill.
- Total assessment does not consider required rates of return and time value of money (e.g. interests, inflation or discount rates).
- The assessment does not consider variation over time in:
  - Landfill gas and electricity generation;
  - The operation and maintenance costs;
  - Wholesale electricity price; and
  - ACCUs and LGCs.

Conclusion 38 For a landfill gas capture, flare and power generation system, over the life of asset considered (seven years), the capital costs represent approximately 50% of the costs and the ongoing costs (e.g. operation and maintenance) represent approximately 30% of the total costs and the power generation overhaul represent approximately 20% of the total costs. For a landfill gas capture and flaring system, these costs would be approximately 40% for the capital costs and 60% for the ongoing costs. This is mainly due to the operation and maintenance requirements of the landfill gas capturing system.

Conclusion 39 ACCUs are a strong incentive for power generating projects. In consideration of the life of asset (seven years), the ACCUs contribute to achieving revenue from both the power generation project and the landfill gas capture and flare project. Nevertheless, without the ACCUs and in consideration of the revenue streams from the sale of electricity for applicable projects, these projects may present a loss over the life of asset.

[91] Estimates only – negative quantities represent costs.
[92] Life of asset has been considered to be seven (7) years, in line with the ERF contract period timeframe.

APPENDICES

APPENDIX A: LEGISLATION

Relevant Legislation
NSW
Protection of the Environment Operations Act 1997
Section 3- Objects of Act The objects of this Act are as follows: (a) to protect, restore and enhance the quality of the environment in New South Wales, having regard to the need to maintain ecologically sustainable development, (b) to provide increased opportunities for public involvement and participation in environment protection, (c) to ensure that the community has access to relevant and meaningful information about pollution, (d) to reduce risks to human health and prevent the degradation of the environment by the use of mechanisms that promote the following: i. pollution prevention and cleaner production, ii. the reduction to harmless levels of the discharge of substances likely to cause harm to the environment, a. the elimination of harmful wastes, iii. the reduction in the use of materials and the re-use, recovery or recycling of materials, iv. the making of progressive environmental improvements, including the reduction of pollution at source, v. the monitoring and reporting of environmental quality on a regular basis, (e) to rationalise, simplify and strengthen the regulatory framework for environment protection, (f) to improve the efficiency of administration of the environment protection legislation, (g) to assist in the achievement of the objectives of the Waste Avoidance and Resource Recovery Act 2001.
Section 120- Prohibition of pollution of waters (1) A person who pollutes any waters is guilty of an offence. Note: An offence against subsection (1) committed by a corporation is an offence attracting special executive liability for a director or other person involved in the management of the corporation-see section 169. (2) In this section: "pollute" waters includes cause or permit any waters to be polluted.
Section 124- Operation of plant (other than domestic plant) The occupier of any premises who operates any plant in or on those premises in such a manner as to cause air pollution from those premises is guilty of an offence if the air pollution so caused, or any part of the air pollution so caused, is caused by the occupier's failure: a. to maintain the plant in an efficient condition, or b. to operate the plant in a proper and efficient manner
Section 125- Maintenance work on plant (other than domestic plant) The occupier of any premises who carries out maintenance work on any plant in or on those premises in such a manner as to cause air pollution from those premises is guilty of an offence if the air pollution so caused, or any part of the air pollution so caused, is caused by the occupier's failure to carry out that work in a proper and efficient manner.
Section 126- Dealing with materials 1) The occupier of any premises who deals with materials in or on those premises in such a manner as to cause air pollution from those premises is guilty of an offence if the air pollution so caused, or any part of the air pollution so caused, is caused by the occupier's failure to deal with those materials in a proper and efficient manner. 2) In this section: "deal" with materials means process, handle, move, store or dispose of the materials. "materials" includes raw materials, materials in the process of manufacture, manufactured materials, by-products or waste materials.

127 Proof of causing pollution To prove that air pollution was caused from premises, within the meaning of sections 124-126, it is sufficient to prove that air pollution was caused on the premises, unless the defendant satisfies the court that the air pollution did not cause air pollution outside the premises.
128 Standards of air impurities not to be exceeded 1) The occupier of any premises must not carry on any activity, or operate any plant, in or on the premises in such a manner as to cause or permit the emission at any point specified in or determined in accordance with the regulations of air impurities in excess of: a. the standard of concentration and the rate, or b. the standard of concentration or the rate, prescribed by the regulations in respect of any such activity or any such plant. (1A) Subsection (1) applies only to emissions ("point source emissions") released from a chimney, stack, pipe, vent or other similar kind of opening or release point. 2) The occupier of any premises must carry on any activity, or operate any plant, in or on the premises by such practicable means as may be necessary to prevent or minimise air pollution if: a. in the case of point source emissions-neither a standard of concentration nor a rate has been prescribed for the emissions for the purposes of subsection (1), or b. the emissions are not point source emissions. 3) A person who contravenes this section is guilty of an offence.
Section 129- Emission of odours from premises licensed for scheduled activities 1) The occupier of any premises at which scheduled activities are carried on under the authority conferred by a licence must not cause or permit the emission of any offensive odour from the premises to which the licence applies. 2) It is a defence in proceedings against a person for an offence against this section if the person establishes that: a. the emission is identified in the relevant environment protection licence as a potentially offensive odour and the odour was emitted in accordance with the conditions of the licence directed at minimising the odour, or b. the only persons affected by the odour were persons engaged in the management or operation of the premises. 3) A person who contravenes this section is guilty of an offence.
VIC
Environment Protection Act 1970
Section 1C- The precautionary principle (1) If there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation. (2) Decision making should be guided by— a) a careful evaluation to avoid serious or irreversible damage to the environment wherever practicable; and b) an assessment of the risk-weighted consequences of various options.
Part VI - Clean Air Section 40- Discharges etc. to comply with policy The discharge or emission of wastes into the atmosphere shall at all times be in accordance with declared State environment protection policy or waste management policy specifying acceptable conditions for discharging or emitting wastes into the atmosphere and shall comply with any standards prescribed therefor under this Act. S. 41 amended by No. 9803 s. 3(a)(b), substituted by No. 10092 s. 14.
Section 41- Pollution of Atmosphere S. 41(1) amended by No. 20/1988 s. 7(d). 1. A person shall not pollute the atmosphere so that the condition of the atmosphere is so changed as to make or be reasonably expected to make the atmosphere— S. 41(1)(a) amended by No. 10261 s. 18(1). a. noxious or poisonous or offensive to the senses of human beings; b. harmful or potentially harmful to the health, welfare, safety or property of human beings; c. poisonous, harmful or potentially harmful to animals, birds or wildlife; d. poisonous, harmful or potentially harmful to plants or other vegetation; or e. detrimental to any beneficial use made of the atmosphere. S. 41(2) amended by Nos 22/1987 s. 22(d), 20/1988 s. 7(e).

2. Without in any way limiting the generality of subsection (1) a person shall be deemed to have polluted the atmosphere in contravention of subsection (1) if—
    a. that person causes or permits to be placed in or so that it may be released into the atmosphere any matter whether solid, liquid or gaseous which—
        i. is prohibited by or under this Act; or
        ii. does not comply with any standard prescribed for that matter; or

S. 41(2)(b) repealed by No. 10261 s. 18(2).
S. 41(2)(b) inserted by No. 30/1989 s. 4(a).

    b. that person causes or permits the discharge or emission of any matter or substance into the atmosphere in contravention of this Act; or
    c. that person uses any chemical substance or fuel the use of which is prohibited by the regulations; or
    d. S. 41(2)(d) inserted by No. 30/1989 s. 4(b).
    e. that person contravenes any regulation dealing with the use of any ozone-depleting substance or the manufacture, assembly, installation, operation, maintenance, removal, sale or disposal of goods, equipment, machinery, or plant containing or using an ozone-depleting substance.

S. 41A inserted by No. 9571
S. 4(1), amended by No. 9758
S. 6, repealed by No. 10092
S. 11(2) (as amended by No. 10160 s. 7(2)).

State Environment Protection Policy (Air Quality Management) No. S240 21/12/2001

Section 11. Ambient Air Quality Objectives

The environmental quality objectives for the purpose of this policy are set out in in Schedule A and Schedule B of State environment protection policy (Ambient Air Quality).

Waste Management Policy (Siting, Design and Management of Landfills) No. S264 12/12/04

Section 14- Works Approval and Licensing

1. Applications for works approvals and licences must comply with the provisions of the policy.
2. All premises that are exempt from either works approvals or licensing must comply with the provisions of the policy.

The Authority will progressively amend existing landfill licences so that they are consistent with the policy.

Section 15- General Requirements

1. Where any provision of the BPEM is inconsistent with the policy, the policy shall prevail.
2. This clause applies to an applicant for or holder of a works approval or licence for a landfill site, unless provided for in Clause 17.
3. An applicant for or holder of a works approval or licence for a landfill site must:
    a. comply with the policy as well as all other relevant State environment protection policies and waste management policies;
    b. meet the objectives of the BPEM; and
    c. meet each required outcome of the BPEM.
4. An applicant for or holder of a works approval or licence for a landfill site should use the suggested measures in the BPEM to demonstrate that subclause (3) will be met.
5. If an applicant for a works approval, licence or licence amendment proposes measures alternative to the suggested measures of the BPEM, the Authority shall not issue the works approval, licence or licence amendment unless the applicant satisfies the Authority that the alternative measures:
    a. meet the requirements of subclause (3); and
    b. provide at least an equivalent environmental outcome to that provided by the suggested measure.

Section 20- Landfill Gas

1. (1) In addition to the obligations contained in Clause 15, the Authority may require a landfill operator to install a landfill gas collection system in existing and/or new landfill cells where:
    a. landfill gas emissions are causing or may cause odours;
    b. landfill gas emissions represent or may represent a hazard; or
    c. it is necessary to reduce greenhouse gas emissions.

QLD
Environmental Protection Act 1994
Section 319- General environmental duty 1. (1) A person must not carry out any activity that causes, or is likely to cause, environmental harm unless the person takes all reasonable and practicable measures to prevent or minimise the harm (the general environmental duty). * Note— * See section 24(3) (Effect of Act on other rights, civil remedies etc.). 2. (2) In deciding the measures required to be taken under subsection (1), regard must be had to, for example— a. the nature of the harm or potential harm; and b. the sensitivity of the receiving environment; and c. the current state of technical knowledge for the activity; and d. the likelihood of successful application of the different measures that might be taken; and e. the financial implications of the different measures as they would relate to the type of activity.
Environmental Protection Regulation 2008
Section 51- Matters to be complied with for environmental management decisions 1. The administering authority must, for making an environmental management decision relating to an environmentally relevant activity, other than a prescribed ERA— a. carry out an environmental objective assessment against the environmental objective and performance outcomes mentioned in schedule 5, part 3, tables 1 and 2; and b. consider the environmental values declared under this regulation; and ba if the activity is to be carried out in a strategic environmental area—consider the impacts of the activity on the environmental attributes for the area under the Regional Planning Interests Act 2014; and c. consider each of the following under any relevant environmental protection policies— i. the management hierarchy; ii. environmental values; iii. quality objectives; iv. the management intent; and d. if a bilateral agreement requires the matters of national environmental significance to be considered—consider those matters. 1A. However, the administering agency is not required to consider the matters mentioned in subsection (1)(d) if the Coordinator-General has, under the State Development Act, section 54Y, issued an environmental approval for the undertaking of all or part of the coordinated project to which the activity relates. 2. For an environmental management decision relating to a prescribed ERA, the administering authority making the decision must— a. carry out an environmental objective assessment against the environmental objective and performance outcomes mentioned in schedule 5, part 3, table 1; and b. consider the matters mentioned in subsection (1)(b), (ba) and (c).
Section 51- Matters to be complied with for environmental management decisions 1. The administering authority must, for making an environmental management decision relating to an environmentally relevant activity, other than a prescribed ERA— a. carry out an environmental objective assessment against the environmental objective and performance outcomes mentioned in schedule 5, part 3, tables 1 and 2; and b. consider the environmental values declared under this regulation; and ba if the activity is to be carried out in a strategic environmental area—consider the impacts of the activity on the environmental attributes for the area under the Regional Planning Interests Act 2014; and c. consider each of the following under any relevant environmental protection policies— i. the management hierarchy; ii. environmental values; iii. quality objectives; iv. the management intent; and

d. if a bilateral agreement requires the matters of national environmental significance to be considered—consider those matters. 1A However, the administering agency is not required to consider the matters mentioned in subsection (1)(d) if the Coordinator-General has, under the State Development Act, section 54Y, issued an environmental approval for the undertaking of all or part of the coordinated project to which the activity relates 2. For an environmental management decision relating to a prescribed ERA, the administering authority making the decision must— a. carry out an environmental objective assessment against the environmental objective and performance outcomes mentioned in schedule 5, part 3, table 1; and b. consider the matters mentioned in subsection (1)(b), (ba) and (c).
SCHEDULE 5, Part 3, Table 1 - Operational Assessment Air Environmental Objective: The activity will be operated in a way that protects the environmental values of air. Performance Outcomes 1. There is no discharge to air of contaminants that may cause an adverse effect on the environment from the operation of the activity 2. All of the following—(a) fugitive emissions of contaminants from storage, handling and processing of materials and transporting materials within the site are prevented or minimised; a. contingency measures will prevent or minimise adverse effects on the environment from unplanned emissions and shut down and start up emissions of contaminants to air; b. releases of contaminants to the atmosphere for dispersion will be managed to prevent or minimise adverse effects on environmental values.
Section 8- Air quality objectives for indicators 1. An air quality objective stated in schedule 1, column 3 for an indicator stated in column 1 and for a period stated in column 4, is prescribed for enhancing or protecting the environmental value stated in column 2 of the schedule for the objective. 2. An air quality objective stated in schedule 1, column 3 must be worked out as an average over the period stated in column 4 for the objective. 3. Despite subsection (1), an environmental value may be enhanced or protected in an area or place if the amount of an indicator in the air environment in the area or place is more than the amount of the air quality objective stated in schedule 1, column 3 for the indicator for not more than the number of days stated in column 5 of the schedule for the indicator. 4. It is intended that the air quality objectives be progressively achieved as part of achieving the purpose of this policy over the long term. 5. This section does not apply to an air emission that may be experienced within a dwelling or workplace if the air emission is released within the dwelling or workplace. 6. In this section— workplace see the Work Health and Safety Act 2011, section 8. Section 9- Management hierarchy for air emissions (1) This section states the management hierarchy for an activity involving air emissions. * Note— See section 51 of the Environmental Protection Regulation 2008. (2) To the extent that it is reasonable to do so, air emissions must be dealt with in the following order of preference— a. firstly—avoid; * Example for paragraph (a)— using technology that avoids air emissions b. secondly—recycle; * Example for paragraph (b)— re-using air emissions in another industrial process c. thirdly—minimise; *Example for paragraph (c)— treating air emissions before disposal d. fourthly—manage. *Example for paragraph (d)— locating a thing that releases air emissions in a suitable area to minimise the impact of the air emissions

Petroleum and Gas (production and safety) Act 2004
Section 72- Restriction on flaring or venting 1. An authority to prospect holder must not flare or vent petroleum in a gaseous state produced under the authority unless the flaring or venting is authorised under this section. 2. (2) Flaring the gas is authorised if it is not commercially or technically feasible to use it— a. commercially under the authority; or b. for an authorised activity for the authority. 3. Venting the gas is authorised if— a. it is not safe to use the gas for a purpose mentioned in subsection (2)(a) or (b) or to flare it; or b. flaring it is not technically practicable.
SA
Environmental Protection Act 1993
Section 25- General environmental duty 1. A person must not undertake an activity that pollutes, or might pollute, the environment unless the person takes all reasonable and practicable measures to prevent or minimise any resulting environmental harm. 2. In determining what measures are required to be taken under subsection (1) regard is to be had, amongst other things, to— a. the nature of the pollution or potential pollution and the sensitivity of the receiving environment; and b. the financial implications of the various measures that might be taken as those implications relate to the class of persons undertaking activities of the same or a similar kind; and c. the current state of technical knowledge and likelihood of successful application of the various measures that might be taken. 3. In any proceedings (civil or criminal), where it is alleged that a person failed to comply with the duty under this section by polluting the environment, it will be a defence— a. if— i. maximum pollution levels were fixed for the particular pollutant and form of pollution concerned by mandatory provisions of an environment protection policy or conditions of an environmental authorisation held by the person, or both; and ii. it is proved that the person did not by so polluting the environment contravene the mandatory provisions or conditions; or b. (b) if— i. an environment protection policy or conditions of an environmental authorisation provided that compliance with specified provisions of the policy or with specified conditions of the authorisation would satisfy the duty under this section in relation to the form of pollution concerned; and ii. it is proved that the person complied with the provisions or with such conditions of an environmental authorisation held by the person. 4. Failure to comply with the duty under this section does not of itself constitute an offence, but— a. compliance with the duty may be enforced by the issuing of an environment protection order; and b. a clean-up order or clean-up authorisation may be issued, or an order may be made by the Environment, Resources and Development Court under Part 11, in respect of non-compliance with the duty; and c. failure to comply with the duty will be taken to be a contravention of this Act for the purposes of section 135

Environment Protection (Air Quality) Policy 2016
Section 15- Taking reasonable and practicable measures to avoid emissions from premises 1. The occupier of premises (other than domestic premises) must ensure that the emission of pollutants to air from the premises is not caused through any failure to take reasonable and practicable measures— a. to maintain fuel-burning equipment, control equipment or any other plant or equipment in an efficient condition; or b. to operate fuel-burning equipment, control equipment or any other plant or equipment in a proper and efficient manner; or c. to carry out maintenance of fuel-burning equipment, control equipment or any other plant or equipment in a proper and efficient manner; or d. to process, handle, move or store goods or materials in or on the premises in a proper and efficient manner. Mandatory provision: Category B offence. In this clause—control equipment means any device that controls, limits, measures, records or indicates air pollution; fuel-burning equipment means any machine, engine, apparatus or structure in which, or in the operation of which, combustible material is burned, but does not include a motor
Section 18- Matters relating to Part 6 of Act 1. In determining any matters under Part 6 of the Act in relation to an activity (including a related development), the Authority must take into account the following matters (to the extent to which they are relevant): a. ground level concentrations—whether the activity has resulted, or may result, in the concentration of a pollutant specified in column 1 of the table in Schedule 2 clause 2 exceeding the maximum concentrations specified in column 4 or 5 for that pollutant over the averaging time specified in column 3 for that pollutant (based on evaluations at ground level using a prescribed testing, assessment, monitoring or modelling methodology for the pollutant and activity); b. odour levels—whether the activity has resulted, or may result, in the number of odour units specified in column 2 of the table in Schedule 3 being exceeded for the number of persons specified in column 1 over a 3 minute averaging time 99.9% of the time (based on evaluations at ground level using a prescribed testing, assessment, monitoring or modelling methodology for the pollutant and activity); c. stack emissions—if the Authority is satisfied that it is not reasonably practicable or feasible to make evaluations in relation to the activity under paragraph (a) or (b)—whether the activity (being an activity specified in column 2 of the table in Schedule 4) has resulted, or may result, in the emission to air of a pollutant specified in column 1 of the table in Schedule 4— i. at a level exceeding that specified for the pollutant in column 3; or ii. in contravention of a requirement (if any) specified for the pollutant in column 4, (based on evaluations at the stack using a prescribed testing, assessment, monitoring or modelling methodology for the pollutant and activity); d. evaluation distances—whether the assessment requirements set out in the document entitled Evaluation Distances for Effective Air Quality and Noise Management 2016 prepared by the Authority give rise to requirements for separation distances between the activity and other premises; e. localised air quality objectives—any localised air quality objectives (within the meaning of clause 14) that apply in relation to the activity; f. any other kind of air pollution—whether the activity has resulted or may result in the pollution of the air in any other manner; g. requirements to be imposed on all relevant persons—the requirements that should, in the event of an environmental authorisation being granted, be imposed on all relevant persons for the purposes of preventing or minimising the pollution of the air or its harmful effects. 2. In this clause— prescribed testing, assessment, monitoring or modelling methodology, for a pollutant or activity, means—

a. (a) a testing, assessment, monitoring or modelling methodology set out for the pollutant or activity in—
   i. Ambient Air Quality Assessment 2016 prepared by the Authority; or
   ii. Emission Testing Methodology for Air Pollution 2012 prepared by the Authority; or
   iii. some other testing, assessment, monitoring or modelling methodology approved by the Authority for the pollutant or activity.

WA

Environmental Protection Act 1986

Section 4A - Object and principles of Act

The object of this Act is to protect the environment of the State, having regard to the following principles —

1. The precautionary principle: Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation. In the application of the precautionary principle, decisions should be guided by —
   a) careful evaluation to avoid, where practicable, serious or irreversible damage to the environment; and
   b) an assessment of the risk-weighted consequences of various options.
2. The principle of intergenerational equity: The present generation should ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of future generations.
3. The principle of the conservation of biological diversity and ecological integrity. Conservation of biological diversity and ecological integrity should be a fundamental consideration.
4. Principles relating to improved valuation, pricing and incentive mechanisms
   a) Environmental factors should be included in the valuation of assets and services.
   b) The polluter pays principle — those who generate pollution and waste should bear the cost of containment, avoidance or abatement.
   c) The users of goods and services should pay prices based on the full life cycle costs of providing goods and services, including the use of natural resources and assets and the ultimate disposal of any wastes.
   d) Environmental goals, having been established, should be pursued in the most cost effective way, by establishing incentive structures, including market mechanisms, which enable those best placed to maximise benefits and/or minimise costs to develop their own solutions and responses to environmental problems.
5. The principle of waste minimisation. All reasonable and practicable measures should be taken to minimise the generation of waste and its discharge into the environment.

NT

Waste Management and Pollution Control Act

Section 12- General environmental duty

1. A person who:
   a. conducts an activity that causes or is likely to cause pollution resulting in environmental harm or that generates or is likely to generate waste; or
   b. performs an action that causes or is likely to cause pollution resulting in environmental harm or that generates or is likely to generate waste, must take all measures that are reasonable and practicable to:
   c. prevent or minimise the pollution or environmental harm; and
   d. reduce the amount of the waste.

TAS

Environmental Management and Pollution Control Act 1994

23A. General environmental duty

1. A person must take such steps as are practicable or reasonable to prevent or minimise environmental harm or environmental nuisance caused, or likely to be caused, by an activity conducted by that person.
2. In determining whether a person has complied with the general environmental duty, regard must be had to all the circumstances of the conduct of the activity, including but not limited to –
   a. the nature of the harm or nuisance or likely harm or nuisance; and

b. the sensitivity of the environment into which a pollutant is discharged, emitted or deposited; and
c. the current state of technical knowledge for the activity; and
d. the likelihood and degree of success in preventing or minimising the harm or nuisance of each of the measures that might be taken; and
e. the financial implications of taking each of those measures.

3. Failure to comply with subsection (1) does not itself constitute an offence or give rise to a civil right or remedy, but if a person has failed to comply with that subsection an environment protection notice may be issued to that person.

Where a person, in relation to an environmentally relevant activity, takes all measures specified, in a code of practice made and approved in accordance with the regulations, as meeting the requirements for compliance with the general environmental duty in respect of the activity, the person is taken to have complied with the general environmental duty in respect of the activity.

Environment Protection Policy (Air Quality) 2004

Part 3 - Environmental Values and Standards

Environmental values

Section 6-

1. Environmental values are the values or uses of the environment that are to be protected.
2. The environmental values to be protected under this Policy are –
   a. the life, health and well-being of humans at present and in the future;
   b. the life, health and well-being of other forms of life, including the present and future health, wellbeing and integrity of ecosystems and ecological processes;
   c. visual amenity; and
   d. the useful life and aesthetic appearance of buildings, structures, property and materials.

ACT

Environmental Protection Act 1997

22 General environmental duty

1. A person must take the steps that are practicable and reasonable to prevent or minimise environmental harm or environmental nuisance caused, or likely to be caused, by an activity conducted by that person.
2. In deciding whether a person has complied with the general environmental duty, regard must first be had, and greater weight must be given, to the risk of the environmental harm or environmental nuisance involved in conducting the activity, and, in addition, regard must then be had to—
   a. the nature and sensitivity of the receiving environment; and
   b. the current state of technical knowledge for the activity; and
   c. the financial implications of taking the steps mentioned in subsection (1); and
   d. the likelihood and degree of success in preventing or minimising the environmental harm or environmental nuisance of each of the steps that might be taken; and
   e. other circumstances relevant to the conduct of the activity.
3. Subject to section 125, section 143 and section 160, failure to comply with the general environmental duty does not of itself—
   a. give rise to a civil right or remedy; or
   b. constitute an offence; or
   c. constitute grounds for action under this Act.

APPENDIX B: GUIDELINES

Guidelines provide information on how landfills should operate to meet acceptable, good or best practice. These may represent a reference for interpreting what compliance with legislative requirements means in the context of a landfill site.
NSW
NSW EPA, Environmental Guidelines: Solid waste guidelines, Second edition, 2016
These guidelines provide guidance for the environmental management of landfills in NSW by specifying a series of 'Minimum Standards'. They involve a mix of design and construction techniques, effective site operations, monitoring and reporting protocols, and post-closure management. The NSW Environment Protection Authority (EPA) will use these guidelines to assess applications for new or varied landfill licences under the Protection of the Environment Operations Act 1997 and to assess issues that arise during the operational and post-closure periods of landfills. The minimum standards in these guidelines apply to general solid waste and restricted solid waste landfills. There are some additional (higher) standards for restricted solid waste landfills, recognising the more highly contaminated nature of those wastes. The minimum standards in these guidelines reflect the following broad goals for landfilling in NSW: ▪ landfills should be sited, designed, constructed and operated to cause minimum impacts to the environment, human health and amenity ▪ the waste mass should be stabilised, the site progressively rehabilitated, and the land returned to productive use as soon as practicable. ▪ wherever feasible, resources should be extracted from the waste and beneficially reused ▪ adequate data and other information should be available about any impacts from the site, and remedial strategies should be put in place when necessary ▪ all stakeholders should have confidence that appropriately qualified and experienced personnel are involved in the planning, design and construction of landfills to high standards. These guidelines combine and replace the existing documents Environmental Guidelines: Solid Waste Landfills (NSW EPA, 1996) and the Draft Environmental Guidelines for Industrial Waste Landfilling (NSW EPA, 1998). The principal legislation governing waste management and landfill disposal of waste in NSW is the Protection of the *Environment Operations Act 1997*.
VIC
VIC EPA, Best Practice Environmental Management: Siting, design, operation and rehabilitation of landfills, 2015
This document is intended to provide guidance for landfill operators to meet the environment protection objectives of the regulatory framework. This is achieved by establishing a hierarchy of objectives, required outcomes and suggested measures for each section of the document. The objectives and required outcomes are derived directly from legislation and must be achieved. The suggested measures are provided to assist with achievement of the objectives and required outcomes. Where a landfill operator believes that an alternative to the suggested measures will achieve the objectives and required outcomes, the operator will need to provide independently assessed evidence supporting the proposed measure with their submission to EPA. Alternatively, if the suggested measures contained in this document are not likely to achieve the objectives and required outcomes, then EPA may require alternative measures to those suggested, which EPA will support with an assessment of why the alternative measures are required. This is most likely to occur where a landfill is located or proposed in a particularly sensitive environment.

QLD
QLD Department of Environment and Heritage Protection, Guideline: Landfill siting, design, operation and rehabilitation, 2013
The department expects the environmental outcomes detailed in the guideline to be achieved by landfill operators to ensure the protection of the environment from all waste disposal activities regardless of size, threshold or location. By moving to a risk based approach, as described later in the document, this guideline recognises that existing and proposed landfill sites are each subject to a different suite of individual site-specific circumstances. The environmental outcomes required by the department are fixed and must be met; however the way in which the outcomes are achieved is not fixed. The department is also committed to introducing elements of best practice environmental management to existing landfilling operations (where they can reasonably be introduced) with the objective of raising the standard and reducing the risk of pollution. Best practice environmental management is defined in Section 21 of the Environmental Protection Act 1994 (EP Act), as '...the management of the activity to achieve an ongoing minimisation of the activity's environmental harm through cost-effective measures assessed against the measures currently used nationally and internationally'. The department will work with landfill operators wherever possible, or use the enforcement tools available under the EP Act if necessary, to introduce best practice environmental management and ultimately increase the level of environmental protection.
SA
SA EPA Guidelines, Environmental management of landfill activities (municipal solid waste and commercial and industrial general waste), January 2007
Development and operation of landfill facilities in South Australia are activities of environmental significance and these activities must be carried out in accordance with the Environment Protection Act 1993 (the EP Act). This guideline is intended to provide guidance to landfill operators, developers, planning authorities and regulatory bodies on the site selection, development, design, construction, operation, closure and post-closure management of municipal solid waste, and commercial and industrial (C&I) general waste landfill facilities so that they can comply with the EP Act. An SA EPA Guideline provides guidance to industry or the community concerning specific issues, and: ▪ is primarily advisory ▪ includes technical information and recommends ways of undertaking an activity: ideas for 'how to' ▪ prescribes an environmental outcome, but is not normally prescriptive about the mechanisms by which an outcome would be achieved, as it seeks to encourage rather than stifle innovation ▪ is intended for internal and external use ▪ is not directly enforceable; however, it may be used to help the EPA interpret the general environment duty for a particular situation, and may be enforced through issuing an EPO, a condition of licence, or a condition of a development approval.
WA
WA Department of Environment Regulation, Environmental Standard: Metropolitan landfills (due for release 2017)
Environmental Standards set out the required levels of environmental performance for regulated activities based on the hierarchy of preventing, controlling, abating and mitigating pollution and environmental harm. DER's Guidance Statement: Regulatory Principles provides high-level principles of good regulatory practice that guide the exercise of DER's environmental regulation functions. This Guidance Statement builds on those regulatory principles by providing greater detail on how DER will apply Environmental Standards to applications for, and conditions on, works approvals and licences. Environmental Standards are part of DER's hierarchy of instruments governing environmental regulation and apply to a range of DER's regulatory functions. This Guidance Statement should be read together with DER's Guidance Statement: Regulatory Principles which contains information on the application of Environmental Standards.

NT
NT EPA Guidelines for siting, design and management of Solid Waste Disposal Sites, in the Northern Territory, 2013
These guidelines have been written to provide guidance to landfill operators, developers, planning authorities and regulatory bodies on the site selection, development, design, construction, operation, closure and post-closure management of municipal solid waste, and commercial and industrial (C&I) general waste landfill facilities so that they can comply with the Waste Management and Pollution Control Act. The purpose of these Guidelines is to provide a consistent and environmentally responsible approach to managing landfills in the Northern Territory. This guide should be used for the planning of environmental approvals and licensing for new landfill sites and expansion of existing landfill sites. It also applies, where appropriate, to existing landfill sites.
TAS
Department of Primary Industries, Water and Environment, Landfill Sustainability Guide, 2004
The Sustainability Guide is designed to help landfill operators achieve good environmental performance. While the Sustainability Guide itself is not a legally enforceable document, permit conditions (which are legally enforceable) are likely to be derived from the acceptable standards and recommendations described within the Sustainability Guide.
ACT
No guidelines available

APPENDIX C: LICENCES

NSW
Protection of the Environment Operations Act 1997
NSW Environmental Protection Authority
The EPA assesses the site-specific risks posed by each licensed activity, in terms of the risks relating to the day-to-day operations as well as the pollution incident risk at the premises. The prior environmental management performance of the licence holder at the premises will also be used to determine the level of risk. The EPA's risk-based licensing system aims to ensure that all environment protection licence holders receive an appropriate level of regulation based on the level of risk that they pose to human health and the environment. Licences may reference: ▪ *NSW EPA, Environmental Guidelines: Solid waste landfills, Second edition, 2016* ▪ *NSW EPA, Environmental Guidelines: Solid waste landfills, 1996* ▪ Site specific landfill environmental management plans (LEMPs) ▪ Site specific pollution limits Separate to the requirements of the licence, general obligations of licensees are set out in the *Protection of the Environment Operations Act 1997* and the Regulations made under the Act. These include obligations to: ▪ ensure persons associated with you comply with this licence, as set out in section 64 of the Act; ▪ control the pollution of waters and the pollution of air (see for example sections 120 - 132 of the Act); ▪ report incidents causing or threatening material environmental harm to the environment, as set out in Part 5.7 of the Act.
VIC
Environment Protection Act 1970
VIC Environmental Protection Authority
EPA requirements for environmental management of landfill operations have changed as part of the licence reform program. These changes have led to landfill licences being less prescriptive and require licence-holders to better identify and manage the environmental impacts of their landfill operations. This shift in responsibility has also increased the requirement for environmental assessments and audits of landfill management activities by environmental auditors appointed under the *Environment Protection Act 197* (environmental auditors). Licences contain standard conditions that aim to control the operation of the premises so that there is no adverse effect on the environment. These conditions address areas such as waste acceptance and treatment, air and water discharges, and noise and odour. The *Environment Protection Act 1970* specifies penalties for breach of licence conditions and for operating a site without a licence. Generally, licence requirements reference the VIC EPA's *Best Practice Environmental Management: Siting, design, operation and rehabilitation of landfills, 2015.*
QLD
Environmentally Relevant Activity (ERA 60) - Environment Protection Act 1994
QLD Department of Infrastructure, Local Government and Planning
All activities that meet the definition for ERA 60 in Schedule 2 of the *Environmental Protection Regulation 2008* (EP Reg), will, regardless of threshold, require an environmental authority to be obtained under the *Environment Protection Act 1994* prior to being able to operate the activity. ERA 60 outlines the model operating conditions provide a framework of conditions that will apply to landfill operations across the State of Queensland. In giving approval under the EP Act for *ERA 60—Waste disposal activities*, the administering authority must address the regulatory requirements set out in the Environmental Protection Regulation 2008 and the standard criteria contained in the EP Act. The administering authority will give consideration to these regulatory requirements in the context of specific information about the environmental impacts of a particular project provided through application documentation for an environmental authority. Conditions in your environmental authority will generally state what is and what is not permitted as part of the activity. They will relate to the operation of the activity and also cover rehabilitation requirements. Generally, the licences reference conditions set out in *VIC EPA Best practice environmental management: Siting, design, operation and rehabilitation of landfills, 2015.*
SA

Environment Protection Act 1993
SA Environmental Protection Authority
The EPA imposes conditions through a licence to regulate activities that have the potential to harm the environment. Any person or company undertaking these types of activities may need an EPA licence, as required by the *Environment Protection Act 1993*. The term of a licence is generally five years, but can vary from one to 10 years based on the EPA's assessment of the risk or duration of the activity. A licence is an enforceable agreement between the EPA and the licensee that sets out the minimum acceptable environmental standards to which the licensee must perform. The EPA considers how high the environmental risk is likely to be from the licensed activities, when setting conditions of the licence. Subsequently, environmental licences are unique and may be developed to focus on any or all of the following objectives: ▪ documentation of the requirements of a licensee under existing regulations ▪ facilitating the attainment of environmental performance standards of the licensee ▪ facilitating the alignment of the behaviour of the licensee with the core environmental objectives required under the Environment Protection Act 1993 and related policies. The Act also requires that all reasonable and practical measures are taken to protect, restore and enhance the quality of the environment, including requiring persons engaged in polluting activities to progressively make environmental improvements. This will affect how the minimum acceptable standards are determined and reflected in licences.
WA
Environmental Protection Act 1986
WA Department of Regulation
The Department of Environment Regulation has responsibility under Part V of the *Environmental Protection Act 1986* for the licensing and registration of prescribed premises, the issuing of works approvals and administration of a range of regulations. DER also monitors and audits compliance with works approvals, licence conditions and regulations, take enforcement actions as appropriate, and develops and implements Departmental licensing and industry regulation policy.
NT
Environment Protection Licence - Waste Management and Pollution Control Act
NT Environment Protection Authority
An Environment Protection Licence is required for Schedule 2 activities under the *Waste Management and Pollution Control Act*. Environment Protection Licences are generally associated with operational activity. Pursuant to Section 30, Part 2 of Schedule 2 of the Waste Management and Pollution Control Act a landfill servicing the waste disposal requirements of more than 1000 persons1 cannot be operated without a Licence. Licence is not required to operate a landfill that services a permanent population of less than 1000 persons that only accepts municipal solid waste (MSW). However facilities that service less than 1000 persons can still use the guide as a tool for effective waste management.
TAS
Environmental Management and Pollution Control Act 1994
TAS Environment Protection Authority
Landfills that receive 100 tonnes or more of solid waste per annum are determined to be a "level 2 activity" under Schedule 2 of the EMPCA. Consequently, regulatory approval is required from the Board for the design and operation of these landfills. To gain approval, proponents must demonstrate that the acceptable standards outlined in the *Landfill Sustainability Guide 2004* will be achieved. Proponents may select the best mix of controls for site development and management to achieve the required outcome and document these in the Development Proposal and Environmental Management Plan (DP&EMP). In general, a DP&EMP will consider the impact of the development and demonstrate the means to mitigate these impacts, and will address issues including (but not limited to) those described within the Sustainability Guide.
ACT
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APPENDIX D: EXCEEDANCE RESPONSES

NSW
Guidelines Requirements
Surface Emissions Monitoring
The threshold level for further investigation and corrective action is 500 parts per million (volume/volume) of methane at any point on the landfill surface for intermediate and finally-capped areas. If methane is detected at levels above 500 parts per million, investigation and corrective actions can include: ▪ repair or replacement of the cover material ▪ flux (emissions) monitoring to quantify emission rates and help identify the extent of gas loss (surface scans give a concentration, not a flow rate) ▪ installation of sub-surface monitoring wells (if not already installed) to gauge the extent of any lateral migration of gas ▪ adjustment or installation of landfill gas controls to extract and treat gas.
Subsurface Monitoring
The threshold levels for further investigation and corrective action are detection of methane at concentrations above 1% (volume/volume) and carbon dioxide at concentrations of 1.5% (volume/volume) above established natural background levels. If methane is detected at concentrations above 1% (volume/volume), the occupier must notify the EPA promptly. Within 14 days of this notification, the occupier must submit a plan to the EPA for further investigation and/or remediation of the elevated gas levels. Depending on the circumstances, this plan may include one or more of the following measures: ▪ an increase in monitoring frequency and/or the installation of additional monitoring wells ▪ volumetric/gas flow determinations to assess the significance of gas generation rates and the potential scale of off-site gas migration ▪ gas accumulation monitoring in enclosed structures located nearby ▪ a revised landfill gas risk assessment, addressing the source, potential gas migration pathways and potential receptors ▪ notifications to potentially affected persons ▪ installation of landfill gas controls at the source and/or receptors.
Gas accumulation in enclosed structures
The threshold level for further investigation and corrective action is detection of methane at concentrations above 1% (volume/volume). If methane is detected at concentrations above 1% (volume/volume), the occupier must notify the EPA within 24 h. Within 14 days of this notification, the occupier must submit a plan to the EPA for further investigation and/or remediation of the elevated gas levels. Depending on the circumstances, this plan may include: ▪ daily testing of the building or enclosed structure until ventilation or other measures have been put in place to eliminate the methane build-up ▪ installation or adjustment of source and receptor landfill gas controls ▪ further sub-surface monitoring to delineate any potential migration of landfill gas.
Additional Licence Requirement
R2.1 Notifications must be made by telephoning the Environment Line service on 131 555. Note: The licensee or its employees must notify all relevant authorities of incidents causing or threatening material harm to the environment immediately after the person becomes aware of the incident in accordance with the requirements of Part 5.7 of the Act. R2.2 The licensee must provide written details of the notification to the EPA within 7 days of the date on which the incident occurred.

VIC
BPEM Guidelines Requirements
The action levels for landfill gas at different monitoring locations are set out in Table 6.4 of the EPA Best Practice Environmental Management Guidelines. When these action levels are exceeded, the landfill operator must notify EPA within 24 hours. The notification is also to advise what action will be taken to address the matter, what further testing will be done to demonstrate effectiveness of the works, anticipated time frame for the works, or when a detailed landfill gas remediation action plan (LFGRAP) would be prepared and forwarded to EPA. EPA need not be advised of an excursion above an action level where only an onsite location was affected and the matter is rectified within 24 hours. Where an action level has been exceeded at an offsite location, or the result indicates that an action level would be exceeded offsite, then the landfill operator must prepare a landfill gas remediation action plan (LFGRAP). When buildings offsite are or may be impacted by landfill gas, the LFGRAP must be verified by an environmental auditor as taking all practicable measures in the circumstances to reduce the risks from the landfill gas to acceptable levels. Notwithstanding the requirement for auditor verification, the draft LFGRAP is to be forwarded to the EPA as soon as practicable. Auditor verification of the draft LFGRAP is not required prior to its submission to the EPA. The following landfill gas levels inside a building, if confirmed, should trigger advised relocation from the building: ▪ 1% v/v methane. The emergency services need to be advised immediately for action consistent with Victoria's emergency management arrangements. EPA and other relevant authorities should also be advised.
Additional Licence Requirement
Condition LI_G2 You must immediately notify EPA of non-compliance with any condition of this licence.
QLD
ERA 60
The duty to notify requires a person to give notice where serious or material environmental harm is caused or there is a risk of such harm and that harm is not authorised by the administering authority. If methane gas levels exceeding methane standards referred to in condition A3 (action criteria within ERA 60) are detected, all necessary steps must immediately be taken to ensure protection of human health.
SA
Licence Requirement
The Licensee must report to the EPA (on EPA emergency phone number 1800 100 833) all incidents causing or threatening serious or material environmental harm, upon becoming aware of the incident, in accordance with section 83 of the Act. In the event that the primary emergency phone number is out of order, the Licensee should phone (08) 8204 2004
WA
General Licence Requirement
2.1.1 The Licensee shall record and investigate the exceedance of any descriptive or numerical limit or target specified in any part of section 2 of this Licence.
WA
Guidelines
Subsurface monitoring
As a minimum, monitoring of each probe should be carried out six monthly until probe gas concentrations have stabilised below 1% by volume methane and 1.5% by volume carbon dioxide. In the absence of buildings within 250 metres of the landfill boundary, the USEPA guidance value, above which gas control is required, is 5% methane in a boundary probe. More frequent monitoring will be required where gas is found in close proximity to properties. In the case of residential properties, permanent gas monitoring equipment may be necessary.

Building monitoring
Where a building is determined to be at potential risk, based on probe monitoring results or other monitoring information, the building should be regularly monitored to check for the presence of landfill gas. During the monitoring, a portable gas sampler should be used to measure methane and carbon dioxide concentrations in all voids and areas in the basement and/or ground floor and wall cavities of the building. If possible, measurements should be made in each location before allowing ventilation to occur (e.g. measure under a door before opening). If landfill gas is detected, the cause should be remedied as soon as practically possible. Generally, if methane in excess of the 10% lower explosive limit is detected, gas control measures will be required. If concentrations are found to exceed 1% by volume methane or 1.5% by volume carbon dioxide, the building should be evacuated, all ignition sources (including electricity) switched off, and remedial work carried out as soon as possible under an approved health and safety plan prior to reoccupation.
TAS
Guidelines Requirements
Further assessment and remediation should be undertaken if subsurface concentrations exceed 1.25% (v/v) or if surface concentrations exceed 500ppm (v/v).
ACT
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APPENDIX E: REFERENCES

References have been provided throughout the document. A consolidated list of the references is provided in this Appendix.

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APPENDIX F: CALCULATIONS SUMMARY

Summary of calculations for section 2.3.2.

2017 estimated data

Details	Data	Units	Source
CH_4 global warming potential	25		NGER Measurement Determination
Energy content of methane	0.038	GJ/m³	S1, NGER (Measurement) Determination, 2016
Density of methane at standard temperature and pressure	0.00068	t/m³	NGER (Measurement) Determination, 2016, 5.4
Energy content of methane	55.57	GJ/t	
Average energy conversion efficiency, landfill gas system	33%		Blue Environment estimate
Conversion factor, GJ to GWh	0.00028		By definition
Proportion of captured methane used for energy recovery	98%		Blue Environment estimate based on experience with NGER data and typical downtime of electricity engines
CH_4:C atomic ratio	1.33		
Emissions destroyed by flare	98%		NGER Measurement Determination
Baseline (regulatory proportion)	30%		
Value per ACCU	$ 11	AUD$	Estimate
Value per MWh electricity + LGC	$ 60	(MWh equiv.)	Assume electricity and LGCs 'bundled' together at $60 based on: Origin PPA $50-$60 http://reneweconomy.com.au/origin-stuns-industry-with-record-low-price-for-530mw-wind-farm-70946/ AGL Silverton windfarm at $65 http://reneweconomy.com.au/agls-new-200mw-silverton-wind-farm-to-cost-just-65mwh-94146/ and assume half each so assume ▪ electricity $30/MWh ▪ LGCs $30/MWh

Methane collected	1,000,000	m³	
	678	t	
CO_2-e emissions equivalent	16,960	t CO_2-e	
Emissions avoided	16,621	t CO_2-e	
Emissions creditable	11,635	t CO_2-e	
Energy content	37,700	GJ	
Energy generated	12,192	GJ	
	3.39	GWh	
Value of ACCUs	**$127,980**	AUD$	39%
Value of electricity generated + LGCs	**$ 203,203**	AUD$	61%

2013 estimated data

Details	Data	Units	Source
CH_4 global warming potential	25		NGER Measurement Determination
Energy content of methane	0.038	GJ/m³	S1, NGER (Measurement) Determination, 2016
Density of methane at standard temperature and pressure	0.00068	t/m³	NGER (Measurement) Determination, 2016, 5.4
Energy content of methane	55.57	GJ/t	
Average energy conversion efficiency, landfill gas system	33%		Blue Environment estimate
Conversion factor, GJ to GWh	0.00028		By definition
Proportion of captured methane used for energy recovery	98%		Blue Environment estimate based on experience with NGER data and typical downtime of electricity engines
CH_4:C atomic ratio	1.33		
Emissions destroyed by flare	98%		NGER Measurement Determination
Baseline (regulatory proportion)	30%		
Value per ACCU	$ 20	AUD$	Estimate, during period when compliance ACCUs fixed price at $23.00 then $24.15
Value per MWh electricity + LGC	$ 120	(MWh equiv.)	Estimated using Figure 5.

Methane collected	1,000,000	m³	
	678	t	
CO_2-e emissions equivalent	16,960	t CO_2-e	
Emissions avoided	16,621	t CO_2-e	
Emissions creditable	11,635	t CO_2-e	
Energy content	37,700	GJ	
Energy generated	12,192	GJ	
	3.39	GWh	
Value of ACCUs	**$232,691**	AUD$	36%
Value of electricity generated + LGCs	**$ 406,406**	AUD$	64%

Scenario 1 – High Bundle – Low ACCU

Details	Data	Units	Source
CH_4 global warming potential	25		NGER Measurement Determination
Energy content of methane	0.038	GJ/m^3	S1, NGER (Measurement) Determination, 2016
Density of methane at standard temperature and pressure	0.00068	t/m^3	NGER (Measurement) Determination, 2016, 5.4
Energy content of methane	55.57	GJ/t	
Average energy conversion efficiency, landfill gas system	33%		Blue Environment estimate
Conversion factor, GJ to GWh	0.00028		By definition
Proportion of captured methane used for energy recovery	98%		Blue Environment estimate based on experience with NGER data and typical downtime of electricity engines
CH_4:C atomic ratio	1.33		
Emissions destroyed by flare	98%		NGER Measurement Determination
Baseline (regulatory proportion)	30%		
Value per ACCU	$ 8	AUD$	Estimate for the Scenario
Value per MWh electricity + LGC	$ 100	(MWh equiv.)	Estimated mid-point in FY14 bar in Figure 5.

Methane collected	1,000,000	m^3	
	678	t	
CO_2-e emissions equivalent	16,960	t CO_2-e	
Emissions avoided	16,621	t CO_2-e	
Emissions creditable	11,635	t CO_2-e	
Energy content	37,700	GJ	
Energy generated	12,192	GJ	
	3.39	GWh	
Value of ACCUs	**$93,076**	AUD$	22%
Value of electricity generated + LGCs	**$338,672**	AUD$	78%

APPENDIX G: VICTORIA LANDFILL LICENCE COMPLIANCE (L5)

Summary of the Victorian landfill compliance with L5 (*You must prevent emissions of landfill gas from exceeding the investigation levels specified in Best Practice Environmental Management, Siting, Design, Operation and Rehabilitation of Landfills (EPA Publication 788)*).

No	Licence No	Licence Name	2013	2014	2015	2016
1	12281	COLAC-OTWAY SHIRE COUNCIL	Yes	Yes	Yes	Yes
2	9089	BAXTER BUSINESS PTY LTD	No	No	No	No
3	11646	ALPINE SHIRE COUNCIL	No results			
4	11650	YARRA RANGES SHIRE COUNCIL	No results			
5	11684	RIVERLEE CARUSO EPPING PTY LTD	NA	NA	No	No
6	11758	B.T.Q GROUP PTY LTD	Yes	Yes	Yes	Yes
7	11789	CALDER PARK RACEWAY PTY LTD	Yes	Yes	Yes	Yes
8	11818	GLEN LANDFILL PTY LTD	Yes	No	No	Yes
9	11848	GEELONG LANDFILL PTY LTD	Yes	Yes	Yes	Yes
10	11879	MOUNT ALEXANDER SHIRE COUNCIL	No	Yes	No	NA
11	11908	ELLIOTT HOLDINGS (AUST) PTY LTD	Yes	Yes	Yes	Yes
12	11940	ALTONA NORTH LANDFILL PTY LTD	Yes	No	Yes	Yes
13	11972	WESTERN LAND RECLAMATION PTY LTD	Yes	Yes	Yes	Yes
14	12008	CITY OF BALLARAT	No	No	Yes	No
15	12039	MURRINDINDI SHIRE COUNCIL	No	No	No	No
16	12067	HORSHAM RURAL CITY COUNCIL	Yes	Yes	Yes	Yes
17	12099	GREATER SHEPPARTON CITY COUNCIL	No	No	No	No
18	12129	BASS COAST SHIRE COUNCIL	No	No	No	Yes
19	12160	LANDFILL OPERATIONS PTY LTD	No	No	No	Yes
20	12192	CORANGAMITE SHIRE COUNCIL	No	No	No	No
21	12247	STRATHBOGIE SHIRE COUNCIL	Yes	No	No	No
22	12275	MANSFIELD SHIRE COUNCIL	No results			
23	12309	HANSON LANDFILL SERVICES PTY LTD	No	No	No	No
24	12339	A.J. BAXTER PROPRIETARY LIMITED	No	No	No	No
25	12380	LYNDCADLE PROPRIETARY LIMITED	Yes	Yes	Yes	Yes
26	12409	CALLEJA PROPERTIES PTY LTD	No results			
27	12450	HUME CITY COUNCIL	Yes	Yes	Yes	Yes
28	12483	WYNDHAM CITY COUNCIL	No	No	No	No
29	12512	A.J. BAXTER PROPRIETARY LIMITED	No	No	No	No
30	12554	CLEANAWAY SOLID WASTE PTY LTD	No results			
31	12560	BENALLA RURAL CITY COUNCIL	No	No	Yes	Yes
32	13111	ALPINE SHIRE COUNCIL	Yes	Yes	Yes	Yes
33	13157	HUME CITY COUNCIL	No results			

No	Licence No	Licence Name	2013	2014	2015	2016
34	15500	MOIRA SHIRE COUNCIL	Yes	No	No	No
35	18883	CLEANAWAY PTY LTD	No	No	No	No
36	19732	YARRA RANGES SHIRE COUNCIL	No results			
37	19951	MILDURA RURAL CITY COUNCIL	Yes	No	No	No
38	20025	WANGARATTA RURAL CITY COUNCIL	No	No	No	No
39	20474	MITCHELL SHIRE COUNCIL	No results			
40	20720	SOUTHERN GRAMPIANS SHIRE COUNCIL	Yes	Yes	Yes	Yes
41	21125	NILLUMBIK SHIRE COUNCIL	No results			
42	21470	SURF COAST SHIRE	No	No	No	Yes
43	22492	GLENELG SHIRE COUNCIL	No	Yes	No	No
44	24430	EAST GIPPSLAND SHIRE COUNCIL	No results			
45	24532	LATROBE CITY COUNCIL	No results			
46	24873	SOUTH GIPPSLAND SHIRE COUNCIL	No	No	No	No
47	25565	LATROBE CITY COUNCIL	No	No	No	No
48	26457	LATROBE CITY COUNCIL	No results			
49	45248	GROSVENOR LODGE PTY. LTD.	Yes	No	No	No
50	45279	HI-QUALITY QUARRY PRODUCTS PTY LTD	No	No	No	No
51	45288	MADDINGLEY BROWN COAL PTY LTD	No results			
52	46490	GREATER BENDIGO CITY COUNCIL	No	No	No	No
53	69939	SUEZ RECYCLING & RECOVERY PTY LTD	No results			
54	70000	CENTRAL GIPPSLAND REGION WATER	No results			
55	70081	GREATER GEELONG CITY COUNCIL	No results			
56	70151	GANNAWARRA SHIRE COUNCIL	No results			
57	70183	STATEWIDE RECYCLING SERVICES	No results			
58	70367	MORNINGTON PENINSULA SHIRE COUNCIL	No results			
59	70422	MORNINGTON PENINSULA SHIRE COUNCIL	No results			
60	70542	SUEZ RECYCLING & RECOVERY PTY LTD	No results			
61	70781	MITCHELL SHIRE COUNCIL	No results			
62	70988	MITCHELL SHIRE COUNCIL	No results			
63	72476	GREATER GEELONG CITY COUNCIL	No results			
64	72505	SWAN HILL RURAL CITY COUNCIL	No results			
65	72611	WELLINGTON SHIRE COUNCIL	No results			
66	72667	EAST GIPPSLAND SHIRE COUNCIL	No results			
67	72786	WELLINGTON SHIRE COUNCIL	No results			
68	72826	EAST GIPPSLAND SHIRE COUNCIL	No results			
69	80195	BARRO GROUP PTY LIMITED	NA	Yes	Yes	Yes

APPENDIX H: QLD LANDFILL LICENCES LFG REQUIREMENTS

Summary of the QLD landfill gas requirements as stipulated in the landfill licences.

ERA 60	Landfill Gas requirements
Waste disposal 1: Operating a facility for disposing of, in a year, the following quantity of waste mentioned in subsection (1)(a)	
a) less than 50,000t	No requirement
b) 50,000t to 100,000t	(P9-25) Where a landfill gas monitoring program identifies migration of landfill gas in concentrations greater than 25% of the lower explosive limit for methane at or beyond the boundary of any area of the licensed place used for waste disposal, a landfill gas extraction, a collection and disposal system must be installed into the waste disposal facility so as to prevent or minimise: (a) landfill gas migration through any perimeter embankment; and (b) any uncontrolled emission of landfill gas to the atmosphere. (P9-26) Landfill gas collected by the landfill gas collection system referred to in condition number (P9-25) may only be disposed of: (a) by passive venting to the atmosphere through gas diffusers; or (b) flared prior to release to the atmosphere; or (c) reused.
c) more than 100,000t but not more than 200,000t	(A2.1) A landfill gas management plan must be developed and implemented. The plan must outline actions and timeframes to achieve the following: 1. minimise emissions of landfill gas to the atmosphere; and 2. monitor and minimise the sub-surface migration of the landfill gas to adjacent areas; and 3. maximise the beneficial re-use of landfill gas; and 4. minimise the risk of people being exposed to landfill gas and it reaching concentrations where there is a risk of combustion; and 5. monitoring landfill gas to identify potential volumes, flow rates and composition and concentrations of constituent gases.
d) more than 200,000t	No requirement
Waste disposal 2: Operating a facility for disposing of, in a year, the following quantity of waste mentioned in subsection (1)(b)	
a) 50t to 2,000t	No requirement
b) more than 2,000t but not more than 5,000t	No requirement
c) more than 5,000t but not more than 10,000t	No requirement
d) more than 10,000t but not more than 20,000t	Management of Landfill Gas: Methane Gas Standards (B10) The release of landfill gas from any facility must be such that the concentration of landfill gas must not exceed: (i) 25 percent of the lower explosive limit for methane when measured in facility structures (but excluding facility structures used for landfill gas control and (ii) landfill gas recovery system components); and (iii) the lower explosive limit for methane at the landfill facility boundary.
e) more than 20,000t but not more than 50,000t	Waste (WA25) The holder of this environmental authority must adopt such practices and procedures as necessary to ensure that the concentration of landfill gas (methane standards) generated by Yeppoon landfill does not exceed: a) 25 percent of the lower exposure limit for methane in facility structures excluding gas control or recovery system components; and b) The lower explosive limit for methane at the landfill facility boundary.

ERA 60	Landfill Gas requirements
	Landfill Gas Management (B3) The holder of this environmental authority must adopt such practices and procedures as necessary to ensure that: (a) the concentration of landfill gas (methane standards) generated by the landfill unit does not exceed 25 percent of the lower explosive limit for methane in useable closed spaces located on the facility excluding any gas control or recovery system components; and (b) the concentration of landfill gas components, other than methane, generated by the landfill does not exceed concentrations which may pose a health risk to persons within useable closed spaces located on the facility excluding gas control or recovery system components. **Refer to Note 1**.
f) more than 50,000t but not more than 100,000t	Some licences have: No requirement
	One licence contained: A landfill gas management plan must be developed and implemented. The plan must outline actions and timeframes to achieve the following: 1. minimise emissions of landfill gas to the atmosphere; and 2. monitor and minimise the sub-surface migration of the landfill gas to adjacent areas; and 3. maximise the beneficial re-use of landfill gas; and 4. minimise the risk of people being exposed to landfill gas and it reaching concentrations where there is a risk of combustion; and 5. monitoring landfill gas to identify potential volumes, flow rates and composition and concentrations of constituent gases.
g) more than 100,000t but not more than 200,000t	The release of landfill gas must not cause environmental harm. Landfill gas is not considered to cause environmental harm if: 1. a landfill gas collection system is installed and maintained when the landfill unit is sufficiently elevated to allow adequate drainage of gas lines, and 2. landfill gas monitoring shows that the release of methane does not exceed the following limits: (a) 500 parts per million at a height of 50mm above the final and intermediate cover surface including the batter slopes of the landfill unit (b) 25 percent of the lower explosive limit when measured in facility structures (but excluding facility structures used for landfill gas control and landfill gas recovery system components), and (c) the lower explosive limit at or beyond the landfill facility boundary, and (d) no adverse effects of are caused by subsurface gas to vegetation within Lagoon Creek, Tea Tree Lagoon and the 200 metre riparian buffer zone from the top bank of these waters. A3-9 A collection system for landfill gas must be installed and maintained to efficiently minimise: 1. any likelihood of any subsurface migration of landfill gas from the landfill unit, and 2. any uncontrolled emission of landfill gas. A3-10 Landfill gas collected by the gas collection system must be incinerated prior to release to the atmosphere or provided or used as a fuel source or collected and stored in a proper and efficient manner for later use.

ERA 60	Landfill Gas requirements
	A3-11 The landfill gas collection system must be installed and maintained when each landfill unit is either sufficiently elevated for collection or when an area has been completed.
h) more than 200,000t	Management of Landfill Gas (B3) A collection system for landfill gas must be installed and maintained to efficiently minimise: i. any likelihood of any subsurface migration of landfill gas from the landfill unit; and ii. any uncontrolled emission of landfill gas. (B4) An interim perimeter active landfill gas collection system for all cells must be installed prior to installation of the final gas collection system. This system is to be installed forthwith after the landfill cell is sufficiently elevated to allow adequate drainage of gas lines. (B5) Landfill gas collected by the gas collection system must be incinerated prior to release to the atmosphere or provided as an alternative fuel source or collected and stored in a proper and efficient manner for later use. (B11) There must be no visible emissions from the landfill gas flare. (B12) The release of landfill gas from the landfill must not exceed: i. 25 percent of the lower explosive limit for methane when measured in landfill facility structures (but excluding landfill facility structures used for landfill gas control and landfill gas recovery system components); and ii. the lower explosive limit for methane at the landfill facility boundary.

Note 1:

The licence includes requirements in consideration of the total tonnes disposed, in this licence, 500,000 tonnes is the threshold.

(B4) Where it is estimated that by the cessation of waste disposal activities 500,000 tonnes or more of waste will be disposed of at the licensed place, the holder of this environmental authority must:

(1)submit to the administering authority for review and comment, a proposal to *implement a landfill gas monitoring program* which is to include details of but not be limited to the following information:

- (a) the depth and location of the proposed landfill gas monitoring piezometers;
- (b) piezometer design and construction details;
- (c) frequency of monitoring;
- (d) determinants to be monitored;
- (e) the time scale proposed for the construction of monitoring wells and the implementation of a monitoring program; and
- (f) the parameters and detection limits of monitoring equipment.

(2) install landfill gas monitoring piezometers and implement a landfill gas monitoring program; and

(3)*install an effective gas collection and control system* into any tipping area where the landfill gas monitoring program detects landfill gas in concentrations greater than:

- (a) 25% of the lower explosive limit for methane in facility structures other than the gas control units or parts thereof; or
- (b) the lower explosive limit for methane at the landfill boundary.

APPENDIX I: COMPARATIVE THEORETICAL ANALYSIS OF THE REGULATORY PROPORTION IN EACH STATE

In the absence of information from project offsets reports (not available to the authors), we carried out a theoretical analysis of the regulatory baseline calculations for three (3) scenarios. The scenarios shown in Table 28, were considered. The scenarios consider three different site sizes (areas) for each state. We therefore calculated the allowable flux and the actual flux (using the NGER calculator). This calculation intends to demonstrate how the regulatory proportion is estimated.

Assumptions:

- The site opened in 2000
- Accepted 100kt/yr comprising 40% MSW (class 1), 40% C&I, 20% C&D
- GWP CH_4: 25 [source: NGER (Measurement) Determination]
- OF: 10% [source: NGER (Measurement) Determination]

Table 28: Illustrative example scenarios considered

Variable/Scenario	**A**	**B**	**C**	**Methane Concentration limit (CH_4 ppm)**	**Permitted methane flux rate ($tCH_4/m^2/hr$)**
Site area (ha)	40 ha	20 ha	10 ha		
Proportion of site under final cover	100%	100%	100%		
Allowable 2017 flux (tCO_2-e) – [$M_{Reg,FI}$]					
NSW, QLD, WA, TAS	243,333	121,667	60,833	500	2.5×10^{-6}
ACT, VIC	29,200	14,600	7,300	100	0.3×10^{-6}
NT, SA	no limit	no limit	no limit	n/a	n/a

The allowable 2017 flux was calculated using equation 22 of the Methodology, which is:

$$M_{Reg,FI} = \frac{8760 \times GWP_{CH_4}}{(1 - OF)} \times \sum_{x} (S_x \times C_x)$$

As an example, for a landfill site in the ACT under scenario A, the following formula would apply.

$$M_{Reg,FI} = \frac{8760 \times 25}{(1 - 0.1)} \times \sum (400{,}000 \times 0.3 \times 10^{-6})$$

The estimated actual 2017 emissions (t CO_2-e) were obtained from the NGER calculator and are presented in Table 29. The estimates assume fluxes per unit area are identical.

Table 29: Estimated annual emissions (i.e. flux through final cover) (t CO_2-e)

State	Estimated annual emissions (t CO_2-e)
QLD, NT (fast degradation rates)	91,887
NSW (intermediate degradation rates)	85,831
ACT, SA, TAS, VIC, WA (slow degradation rates)	60,721

Table 29 provides a summary of the outcome of scenario testing which have been estimated based on the regulatory proportions for theoretical landfills by jurisdiction. To obtain those results, the following formula was used:

$$Regulatory\ Proportion = 1 - \frac{Allowable\ 2017\ flux}{Flux\ through\ final\ cover}$$

As an example, for a landfill site in the ACT under scenario A, the following formula would apply.

$$Regulatory\ Proportion = 1 - \frac{29{,}200\ tCO_2e}{60{,}721\ tCO_2e} = 1 - 0.48 = 0.52 = 52\%$$

Table 30: Regulatory proportion

State	A	B	C
ACT	52%	76%	88%
NSW	0%	0%	29%
NT	0%	0%	0%
QLD	0%	0%	34%
SA	0%	0%	0%
TAS	0%	0%	0%
VIC	52%	76%	88%
WA	0%	0%	0%

The three scenarios for each State is presented in *Figure 26*. The default baseline is also highlighted.

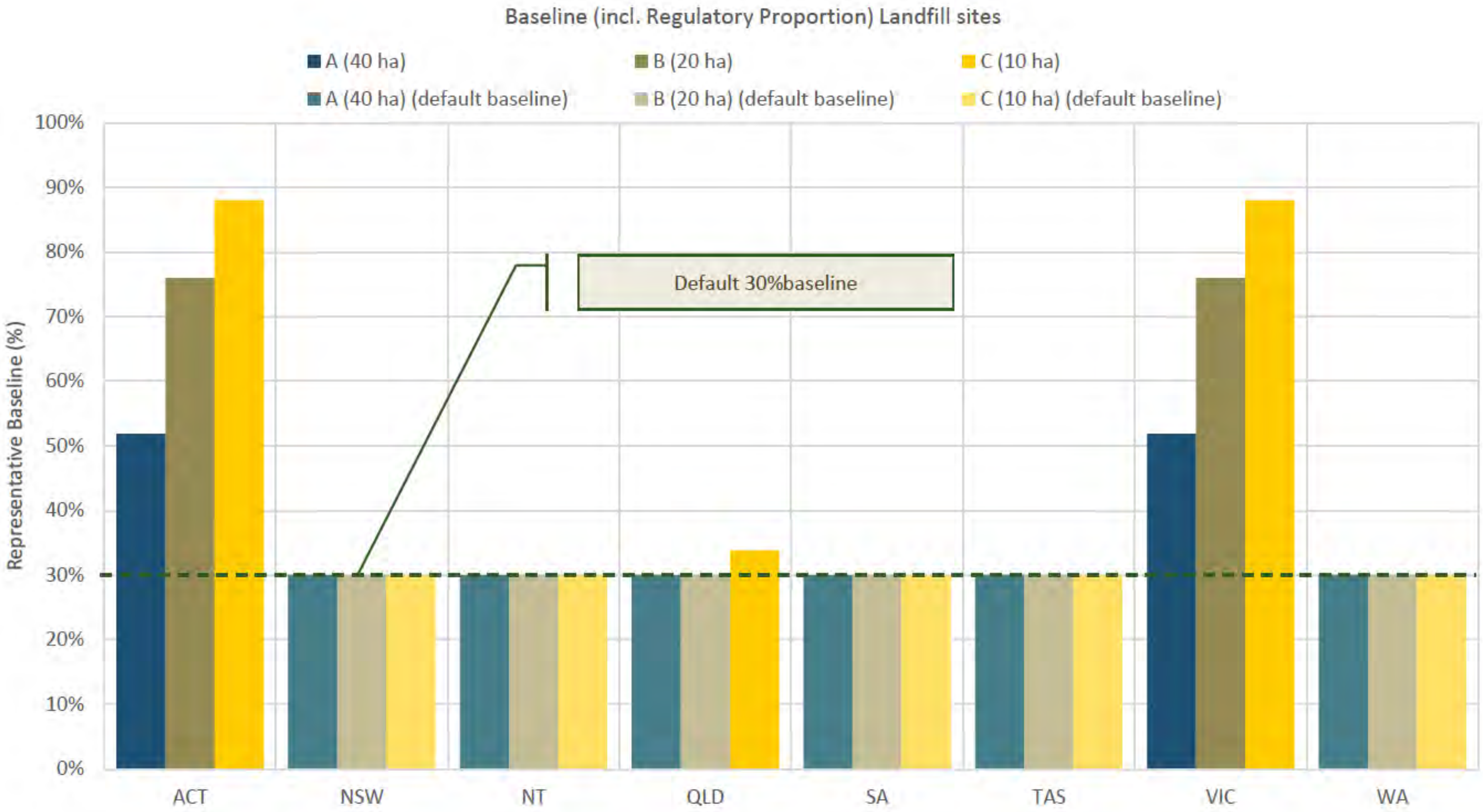

Figure 26: Outcome of scenario testing (graphical) – estimated proportions by State