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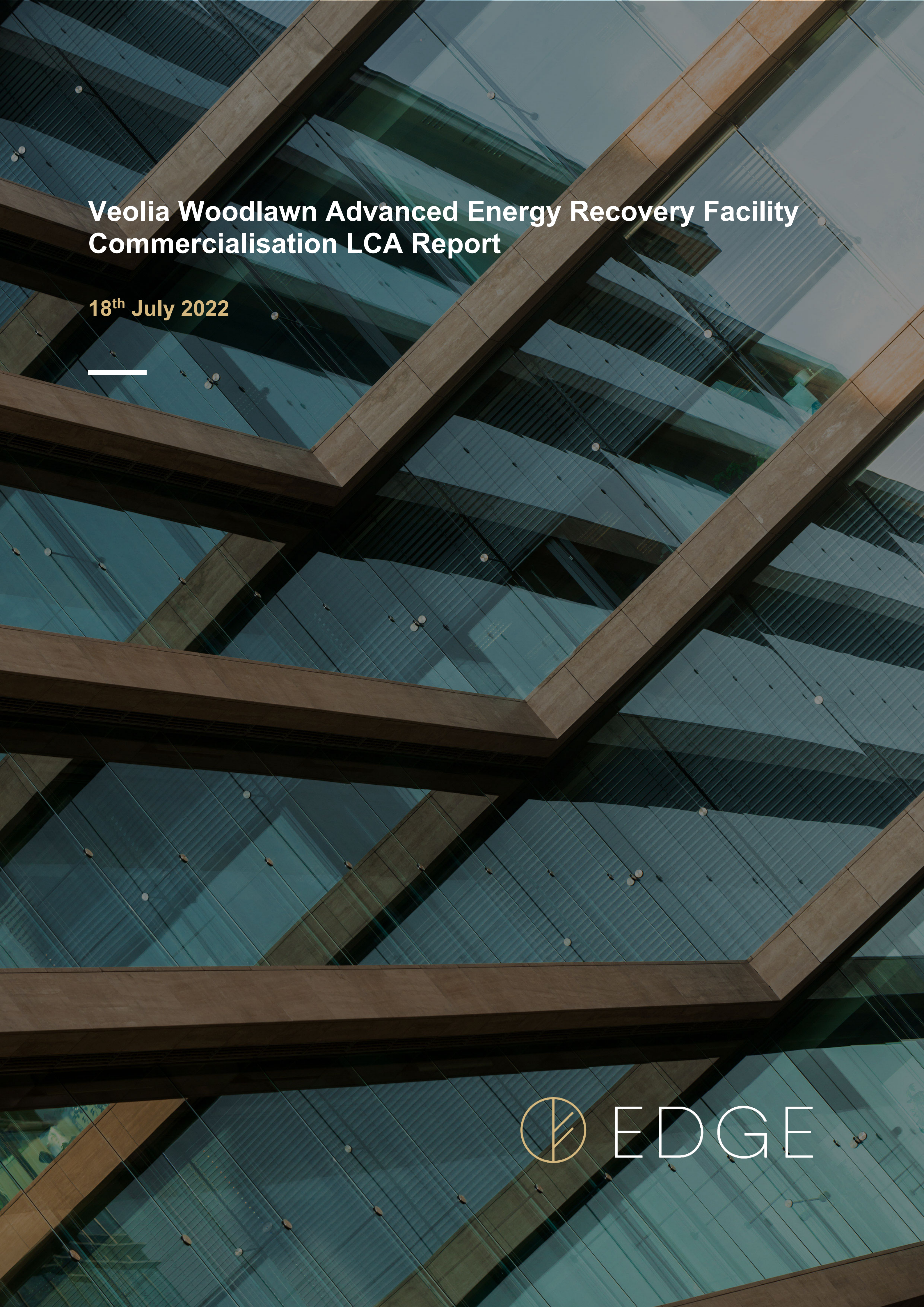
Appendix R

Life cycle analysis



Veolia Woodlawn Advanced Energy Recovery Facility Commercialisation LCA Report

18th July 2022

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Disclaimer:

Executive Summary

The Woodlawn Advanced Energy Recovery Centre (ARC) project involves construction and operation of an energy recovery facility (ERF) that will process residual Municipal Solid Waste (MSW) and Commercial and Industrial (C&I) wastes up to 380,000 tonnes per annum.

The project is expected to generate up to 240,000 megawatt hours (MWh) of electricity per annum. Accounting for parasitic loss, the exportable electricity is expected to be up to 219,830 MWh per annum. The project is classified as a State Significant Development (SSD) under the *Environmental Planning and Assessment Act 1979* (EP&A Act) in accordance with Schedule 1 of State Environmental Planning Policy (Planning Systems) 2021 (PS SEPP).

As a part of Secretary's Environmental Assessment Requirements (SEARs) for the project, the NSW Department of Planning and Environment (DPE) requires a life cycle assessment (LCA) in line with the Australian Renewable Energy Agency (ARENA) guidelines: *Method and guidance for undertaking life cycle assessment of bioenergy products and projects* ("the ARENA Method") (Edge Environment; Life Cycle Strategies, 2017).

Edge Environment was engaged by EMM Consulting and Veolia to undertake a commercialisation LCA for the Woodlawn ARC project to meet the requirements of the DPE for ERF projects to conduct an LCA.

This report provides a commercialisation LCA for Woodlawn ARC project. The LCA is aligned with the guidance for commercialisation LCAs from ARENA, *Method and guidance for undertaking life cycle assessment (LCA) of bioenergy products and projects*, as well as the ISO standards for LCA: ISO 14040:2006 and ISO14044:2006+A1:2018. This LCA can subsequently be used as a basis in the commercialisation stage and refined with revised data as well as peer reviewed as per ARENA requirements and guidelines.

The results of the LCA show that the residual MSW and C&I waste-based power generation system performs better across all environmental impact categories compared to both coal and biomass-based power generation systems. When comparing with a natural gas-based power generation system, MSW and C&I waste-based power generation system showed superior performance in all environmental impact categories except acidification.

The residual MSW and C&I waste-based power generation system results in 183% emissions reduction (GHG-total) compared to a coal-based power generation system. When compared to biomass-based and natural gas-based electricity generation, the emissions reduction (GHG-total) values are 160% and 218%, respectively. This reduction is primarily due to avoided landfilling of residual MSW and C&I wastes. The predicted annual GWP-total savings from the Woodlawn ARC project is 395,034 tonnes of CO_2 eq. when compared to electricity production using hard coal. When compared to biomass-based and natural gas-based electricity generation, the annual GWP-total savings are 481,410 and 331,506 tonnes of CO_2 eq., respectively. The results indicate that the environmental impact hotspots are primarily based in the process for electricity production from thermal treatment of residual MSW and C&I wastes.

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List of acronyms and terms

Acronym or Term	Definition
ALCAS	Australian Life Cycle Assessment Society
ARENA	Australian Renewable Energy Agency
ARENA Method	Method and guidance for undertaking life cycle assessment (LCA) of bioenergy products and projects (Edge Environment; Life Cycle Strategies, 2017)
Embodied Impacts	All the included environmental impacts for a certain object, material, or process.
ARC	Advanced Energy Recovery Centre
ERF	Energy recovery facility
GWP	Global Warming Potential
ODP	Ozone Layer Depletion
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
MSW	Municipal Solid Waste
C&I	Commercial and Industrial waste
IBA	Incinerator bottom ash
APCr	Air pollution control residues
DPE	NSW Department of Planning and Environment
SEARs	Secretary’s Environmental Assessment Requirements
SSD	State significant development
PS SEPP	State Environmental Planning Policy (Planning Systems)

1 Introduction

Edge Environment was engaged by EMM Consulting and Veolia to undertake a commercialisation life cycle assessment (LCA) for the Woodlawn Advanced Energy Recovery Centre (ARC) project to meet the requirements of the NSW Department of Planning and Environment (DPE) for energy-from-waste projects to conduct an LCA. The project is classified as a State significant development (SSD) under the *Environmental Planning and Assessment Act 1979* (EP&A Act) in accordance with Schedule 1 of State Environmental Planning Policy (Planning Systems) 2021 (PS SEPP). The project is of a type listed in Schedule 1 of the PS SEPP, namely it meets the definition of both 'Electricity generating works and heat or co-generation' (clause 20) and 'waste and resource management facilities' (clause 23).

The project will employ residual MSW and C&I wastes to produce electricity with a generation capacity up to 30 MW. The location of the project is approximately 6 km west of the village of Tarago, and 40 km south of Goulburn, NSW. The project offers a range of potential benefits, including a solution to recover energy resources from non-recyclable residual waste generated in NSW, while diverting non-recyclable waste from landfill without increasing the demand for waste disposal.

As a part of Secretary's Environmental Assessment Requirements (SEARs) for the project, DPE requires a LCA in line with the Australian Renewable Energy Agency (ARENA) guidelines: *Method and guidance for undertaking life cycle assessment of bioenergy products and projects* ("the ARENA Method") (Edge Environment; Life Cycle Strategies, 2017).

2 Goal and Scope

The purpose of this study is to provide insights on the environmental impacts (aligned with ARENA guidelines) of the energy-from-waste pathway proposed by EMM Consulting and Veolia. Besides profiling the energy-from-waste pathway, the LCA compares it with 1) conventional coal-derived electricity generation, 2) biomass-based electricity generation and 3) natural gas-fired electricity generation.

The LCA fulfils the SEARs requirement for the project. The audience for the study will be the NSW DPE and stakeholders with an interest in this project. This project involves the construction and operation of a residual MSW and C&I waste-based electricity generation system.

With many examples of waste-based electricity generation systems operational overseas, the scope of the LCA commercialisation study corresponds to the project's stage on the ARENA Technology Readiness Level (TRL) and Commercial Readiness Index (CRI):

- **TRL 9+**
- **CRI 4**

The detailed descriptions of TRL and CRI can be found in Figure 1.

Figure 1 – Technology Readiness Level (TRL) and Commercial Readiness Index (CRI) (Image source: The ARENA Method)

2.1 System boundary and cut off criteria applied.

As per the ARENA Method (Figure 2), capital equipment has been excluded from the LCA. The project requires constructing and maintaining 1 km dedicated road. This has been included in the LCA.

The embodied impacts of capital equipment and infrastructure may be excluded from the LCA without further justification, except for:

- Production systems estimated to have an economic life of less than 10 years.
- Production systems requiring establishment of significant supporting physical infrastructure, such as dedicated roads, rail, pipelines and inter-modal change facilities.

For systems fitting either qualifier above, capital equipment and infrastructure shall be included at a scoping level in the LCA.

Figure 2 – Cut-off rule guidelines (Source: The ARENA Method)

The Woodlawn Advanced Energy Recovery Centre (ARC) project LCA accounts for all known inputs and outputs (i.e., no known inventory items were omitted due to the cut-off criteria). For hard coal electricity production, data from AusLCI was used as-is with no additional cut-off considerations.[1] For natural gas-based electricity production, data from AusLCI was used as-is with no additional cut-off

[1] Electricity, hard coal, at power plant/NORDEL U/AusSD U ReGroup

considerations.[2] For biomass-based electricity production, data from EF Database[3] (Australia specific data) was used as-is with no additional cut-off considerations.[4] Overall, the cut-off criteria employed for LCA in this report is compliant with ARENA LCA guidelines. A diagram of the system boundary is presented in Figure 3.

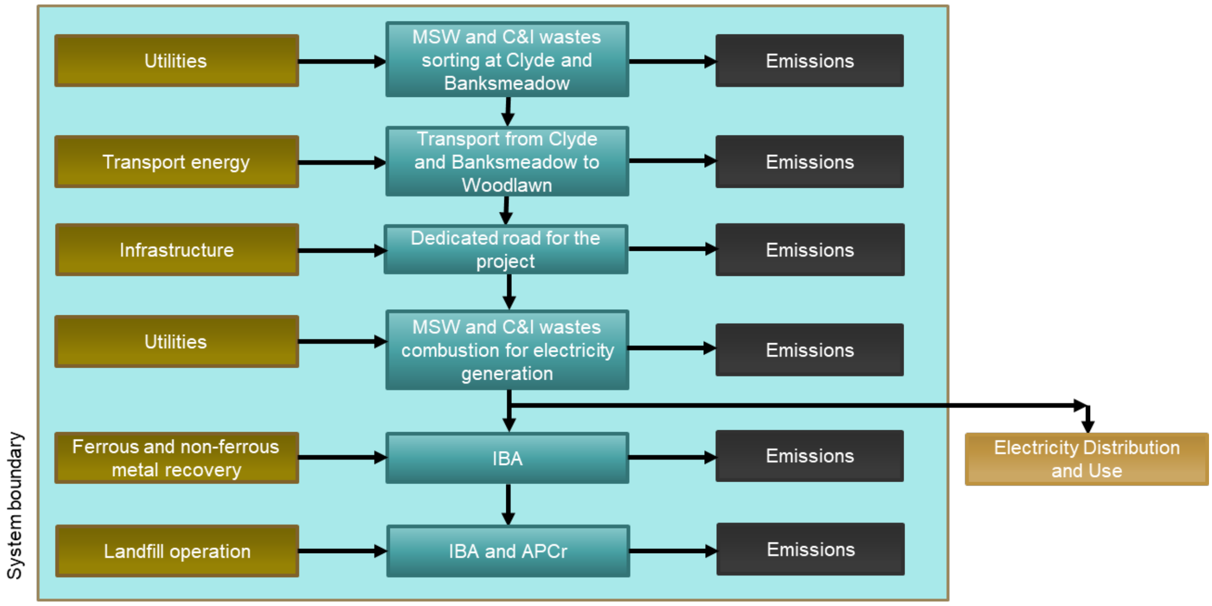

Figure 3: System boundaries. The boxes indicate the main stages of the LCA, with inputs to the left and outputs to the right.

3 Methodology

The LCA was performed in accordance with:

- The Method and guidance for undertaking life cycle assessment (LCA) of bioenergy products and projects ("the ARENA Method") (Edge Environment; Life Cycle Strategies, 2017). Specifically, the ARENA Method's requirements for commercialisation-stage LCAs were adhered to in the LCA study.
- ISO 14040:2006 and ISO14044:2006+A1:2018 which describe the principles, framework, requirements for conducting an LCA (ISO, 2006; ISO, 2018).

3.1 Functional unit and system boundary

The LCA models a system where residual MSW and C&I wastes are initially sorted in two locations (Clyde and Banksmeadow Transfer Terminals) in Sydney, NSW (EMM Consulting: Woodlawn Advanced Energy Recovery Centre, Scoping Report, 2021). The residual MSW and C&I wastes are then transported to Woodlawn ARC near Tarago NSW by train, and then truck. The residual waste will be combusted in Woodlawn ARC for generating electricity and the resulting ashes will be treated and placed in landfill. The system boundaries are shown in Figure 3.

The LCA runs from cradle-to-grave, which includes the:

- sorting of residual MSW and C&I wastes;
- transport of the sorted MSW and C&I wastes to Woodlawn ARC;

[2] Electricity, natural gas, at power plant/AT U/AusSD U

[3] EF database, version 2.0, 2018

[4] Electricity from biomass (solid) {AU} | AC, mix of direct and CHP, technology mix regarding firing and flue gas cleaning | production mix, at power plant | 1kV - 60kV | LCI result

- construction and maintenance of dedicated road;
- thermal treatment of residual MSW and C&I to produce electricity;
- recovery of ferrous and non-ferrous metals; and
- disposal of IBA and treatment and disposal of APCr as landfill.

The functional unit of this study is the production of 1 MWh from residual MSW and C&I wastes at Woodlawn ARC. The LCA results are benchmarked against:

1) 1 MWh from hard coal-based electricity generation,

2) 1 MWh biomass-based electricity generation and

3) 1 MWh natural gas-fired electricity generation.

Whilst initially the IBA may need to be disposed of in the Bioreactor, Veolia intends to use it for beneficial purposes in the future. The first option is to use this as a daily soil cover in the Bioreactor, replacing the clean soil currently imported to the site for this purpose. After further research and development, it might also be approved for use as an aggregate in the construction industry, as commonly occurs overseas. These future uses have not been included in the scenario for this LCA.

3.2 Data sources and quality assessment

Majority foreground data for all processes were sourced from Veolia and EMM Consulting. Foreground data was retrieved in consultation with Veolia and EMM Consulting from:

- Engineering estimates provided by Veolia and EMM Consulting.

A list of foreground data sources and their geographic relevance to the project is provided in Table 1. The quality assessment of the foreground data is based on technical and geographic scopes.

Table 1 – Foreground data – Woodlawn Advanced Energy Recovery Centre (ARC) project – sources and quality

Stage	Input/output	Data source	Quality
Sorting of MSW and C&I wastes	Feedstock- MSW and C&I wastes	Quantities provided by Veolia and EMM Consulting.	High
	Utilities for sorting	Quantities provided by Veolia and EMM Consulting.	High
Transport of MSW and C&I wastes to power generation plant	Clyde and Banksmeadow Transfer Terminals to Woodlawn ARC	Distance estimated based on available travel routes between the origin and destination.	High
Infrastructure	Dedicated road for the project	Data provided by Veolia and EMM Consulting.	High
Power generation at Woodlawn ARC	Process Water	Quantities provided by Veolia and EMM Consulting.	High
	Diesel		
	Hydrate Lime		
	Activated Carbon		
	Aqueous ammonia		
	Air emission		
Metal recovery	Ferrous and non-ferrous metal recovery	Quantities provided by Veolia and EMM Consulting.	High
IBA and APCr landfill	Truck and conveyor transport	Quantities provided by Veolia and EMM Consulting.	High

Generic data was used to model background processes. They were primarily sourced from AusLCI database (Australian National Life Cycle Inventory Database, AusLCI, version 1.31, 2019). Published research paper was used to model a process as the process was not available in AusLCI database (metal recovery as detailed in Table 3). In addition, a number of processes were sourced from ecoinvent (version 3.6, 2019; Table 3)

In addition, Edge complied with the additional five criteria in selecting data for modelling:

- **Relevance:** select sources, data, and methods appropriate to assessing the chosen product's LCI.
- **Completeness:** include all LCI items that provide a material's contribution to a product's life cycle emissions.
- **Consistency:** enable meaningful comparisons in life cycle impact assessment (LCA) information.
- **Accuracy:** reduce bias and uncertainty as far as is practical.
- **Transparency:** when communicating, disclose enough information to allow third parties to make decisions.

3.3 Allocation

Recyclable waste feedstocks at the point of sorting were excluded from the LCA calculation as a conservative approach (otherwise an avoided production credit). This was motivated by the fact that recyclables include different types of products and the collective fate of this output is uncertain.

Whilst initially the IBA may need to be disposed of in the Bioreactor, Veolia intends to use it for beneficial purposes in the future. The first option is to use this as a daily soil cover in the Bioreactor, replacing the clean soil currently imported to the site for this purpose. After further research and development, it might also be approved for use as an aggregate in the construction industry, as commonly occurs overseas. These future uses have not been included in the scenario for this LCA.

The dominant environmental benefits arise from landfill avoidance of residual MSW and C&I wastes in the LCA. The second environmental benefit arises from the recycling of ferrous and non-ferrous metals (recovered from IBA). Both of these benefits were accounted for in the analysis.

Embodied impacts of capital equipment were excluded from the LCA because the production systems have an estimated lifespan greater than 10 years. Embodied impacts of infrastructure (dedicated road) were included in the LCA. These approaches are in line with ARENA's LCA guidance for bioenergy projects.

As per ARENA's LCA guidance for bioenergy projects when residual waste is used as a feedstock the environmental impacts associated with its handling and processing shall be included in the LCA. Furthermore, any avoided impacts from the reduction of landfilling the waste feedstock will be included in the LCA.

3.4 Modelling and impact categories

The inventory data (sourced from Veolia) for the processes were entered in the SimaPro® LCA software (v9.1.1.1) and linked to the pre-existing background data for upstream feedstocks and services. The impact categories (Table 2) were modelled in SimaPro® and the assessment methods comply with the ARENA Method's guidance: "Characterisation models should be sourced from the Best Practice Guidance for Life Cycle Impact Assessment published by the Australian Life Cycle Assessment Society (ALCAS) or as stipulated in Appendix B".

The benefit of avoided landfill of residual MSW and C&I wastes was included in the impact assessment as the source of feedstock is residual waste. This benefit is included as a credit to the system (a negative impact)[5] for the quantity of MSW that is recovered as residual MSW and C&I wastes.

[5] Unit process from AusLCI: Disposal, municipal solid waste, 22.9% water, to sanitary landfill/CH U/AusSD U

Table 2 - Impact categories and assessment methods.

Impact category	Measurement unit	Assessment method	Reference
Climate change, fossil	kg CO_2-eq	IPCC 2013 GWP 100a v1.03	ALCAS Best Practice and ARENA Method
Climate change, biogenic	kg CO_2-eq	IPCC 2013 GWP 100a v1.03	ALCAS Best Practice and ARENA Method
Fossil fuels resource depletion	kg oil equivalents	ReCiPe 2016 Midpoint (H) v1.1[6]	ARENA Method
Fossil fuel energy use (net calorific value)	MJ NCV	CML-IA baseline (3.04) v4.2	ALCAS Best Practice and ARENA Method
Particulate matter formation	kg PM 2.5 eq	ReCiPe 2016 Midpoint (H) v1.1	ARENA Method
Eutrophication	kg phosphate equivalent	CML-IA baseline (3.04) v4.2	ALCAS Best Practice and ARENA Method
Photochemical oxidation	kg C_2H_4 eq	Photochemical Ozone Creation Potentials (POCP) in C2H4-eq based on CML-IA V4.8 August 2016	ALCAS Best Practice and ARENA Method
Ozone layer depletion (ODP)	kg CFC-11 eq	World Meteorological Organisation (WMO) and defines ozone depletion potential of different gases (kg CFC-11 equivalent/ kg emission)	ALCAS Best Practice and ARENA Method
Acidification	kg SO_2 eq	European characterisation factors (Huijbregts, 1999) in kg SO2-eq based on CML-IA V4.8 August 2016	ALCAS Best Practice and ARENA Method
Consumptive water use	m^3 H_2O-eq	Method of Ridoutt and Pfister (2010), with water stress indices of Pfister et al. (2009)	ALCAS Best Practice and ARENA Method
Land use	kg C deficit	ILCD 2011 Midpoint v1.09	ARENA Method

3.5 Sensitivity analysis

The sensitivity of the LCA results was tested on the assumption that the fuel consumption in sorting of residual MSW and C&I wastes can vary significantly (Larsen, 2009). The diesel consumption was varied from 1.5 times to 3 times of baseline and the results are presented in section 5.5.

3.6 Critical review

The ARENA Method states that: "An ISO 14044 compliant critical review of the commercialisation LCA shall be undertaken". Jonas Bengtsson of Edge Environment conducted a critical review of the LCA report. Jonas was not involved in the study in any capacity, and the review was therefore independent. Jonas is a Life Cycle Assessment Certified Practitioner (LCACP), as administered by Australian Life

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[6] This assessment method complies with the ARENA Method Appendix B suggested characterisation factors as it contains the latest fossil energy carriers based on relative scarcity. While the ARENA Method references the previous version of ReCiPe we have used the latest version for the most up to date factors.

Cycle Assessment Society (ALCAS), therefore meeting the requirements of the ARENA Method. Please refer to Appendix B for the critical review report.

4 Life cycle inventory

The inventory compiles the material and energy flows to be accounted for in the LCA. Foreground data was retrieved in consultation with Veolia and EMM Consulting. All inventory data including sources are provided in

Table 3. The reference system used was electricity from black coal, as per ARENA LCA guidelines. However, the project was also benchmarked against biomass-based electricity generation as well as natural gas-fired electricity generation.

Background data for the energy from waste pathway and the fossil-based benchmark was retrieved from the Australian Life Cycle Assessment database (Australian Life Cycle Inventory Database Initiative (AusLCI), 2016), which is representative of the Australian industry. Published research paper was used to model a process as the process was not available in AusLCI database (metal recovery as detailed in Table 3). In addition, several processes were sourced from ecoinvent (version 3.6, 2019; Table 3) as they are also not available in AusLCI.

Table 3 - Life Cycle Inventory for 1 MWh MSW and C&I - based power generation system

	Item	Amount	Unit	Reference	Background data
Input	Electricity for MSW and C&I waste sorting at Clyde[7]	5.40	kWh	Primary data, Veolia and EMM Consulting	Electricity, low voltage, New South Wales/AU U
	Diesel for MSW and C&I waste sorting at Clyde	0.61	L	Primary data, Veolia and EMM Consulting	Energy, from diesel/AU U
	Process water for MSW and C&I waste sorting at Clyde	0.0069	m^3	Primary data, Veolia and EMM Consulting	Water, completely softened, at plant/RER U/AusSD U
	Electricity for MSW and C&I waste sorting at Banksmeadow	3.94	kWh	Primary data, Veolia and EMM Consulting	Electricity, low voltage, New South Wales/AU U
	Diesel for MSW and C&I waste sorting at Banksmeadow	0.52	L	Primary data, Veolia and EMM Consulting	Energy, from diesel/AU U
	Process water for MSW and C&I waste sorting at Banksmeadow	0.0051	m^3	Primary data, Veolia and EMM Consulting	Water, completely softened, at plant/RER U/AusSD U
	Rail transport of MSW and C&I waste from Clyde to Crisps Creek Intermodal facility[8]	100	tkm	Primary data, Veolia and EMM Consulting	Transport, freight, rail/RER U/AusSD/Link U
	Rail transport of MSW and C&I waste from Banksmeadow to Crisps Creek Intermodal facility[9]	322	tkm	Primary data, Veolia and EMM Consulting	Transport, freight, rail/RER U/AusSD/Link U
	Truck transport of MSW and C&I waste from Crisps Creek Intermodal facility to Woodlawn ARC[10]	15.8	tkm	Primary data, Veolia and EMM Consulting	Transport, lorry 16-32t, EURO5/RER U/AusSD U
	Dedicated road construction[11]	25	kmy	Primary data, Veolia and EMM Consulting	Road {RoW}| road construction | Cut-off, U
	Dedicated road maintenance[11]	25	kmy	Primary data, Veolia and EMM Consulting	Road maintenance {RoW}| road maintenance | Cut-off, U

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[7] The densities of MSW and C&I wastes are considered to be 350 kg/m^3 and 400 kg/m^3, respectively.

[8] Distance between Clyde and Crisps Creek Intermodal facility is 252 km.

[9] Distance between Banksmeadow and Crisps Creek Intermodal facility is 271 km.

[10] Distance between Crisps Creek Intermodal facility and Woodlawn ARC is 10 km.

[11] Dedicated road length is 1 km; project life is 25 years.

	Item	Amount	Unit	Reference	Background data
	Electricity for Moving Grate Furnace (incinerator) start-up and outages	4.7	kWh	Primary data, Veolia and EMM Consulting	Electricity, voltage, New South Wales/AU U
	Diesel for power generation	1.25	L	Primary data, Veolia and EMM Consulting	Energy, from diesel/AU U
	Process water for power generation	0.29	m^3	Primary data, Veolia and EMM Consulting	Water, completely softened, at plant/RER U/AusSD U
	Hydrated lime for power generation	22	kg	Primary data, Veolia and EMM Consulting	Lime, hydrated, packed, at plant/CH U/AusSD U
	Activated carbon for power generation	0.48	kg	Primary data, Veolia and EMM Consulting	Activated carbon, granular {GLO}| market for activated carbon, granular | Cut-off, U
	Aqueous ammonia (50%, w/w) for power generation	6	kg	Primary data, Veolia and EMM Consulting	Urea compounds, at plant/AU U and Water, completely softened, at plant/RER U/AusSD U (50/50, w/w)
	Truck Transport of incinerator bottom ash from Ash Maturation Area to Bioreactor	0.10	tkm	Primary data, Veolia and EMM Consulting	Transport, lorry 16-32t, EURO5/RER U/AusSD U
	Conveyor Transport of incinerator bottom ash from Woodlawn ARC to IBA Area	0.03	tkm	Primary data, Veolia and EMM Consulting;	Transport with conveyor, modelled with utility requirement from Kawalec et. Al., Energies, 2000, 13(19), p.5214.
	Truck Transport of air pollution control residues (APCr) from Woodlawn ARC to APCr Encapsulation Cell	0.06	tkm	Primary data, Veolia and EMM Consulting	Transport, lorry 16-32t, EURO4/RER U/AusSD U
Output	Incinerator bottom ash (IBA), post metal recovery	0.28	tonne	Primary data, Veolia and EMM Consulting	Disposal, hard coal ash, 0% water, to residual material landfill/AT U/AusSD U
	Air pollution control residues (APCr)	0.06	tonne	Primary data, Veolia and EMM Consulting	Disposal, hard coal ash, 0% water, to residual material landfill/AT U/AusSD U
	MSW and C&I waste thermal plant emissions to air	0.61	tonne	Primary data, Veolia and EMM Consulting	Modelled using data provided by Veolia and EMM Consulting
Avoided landfilling	MSW, avoided emissions to air	1.27	tonne	Primary data, Veolia and EMM Consulting	Disposal, municipal solid waste, 22.9% water, to sanitary landfill/CH U/AusSD U[12]
	C&I wastes, avoided emissions to air	0.32	tonne	Primary data, Veolia and EMM Consulting	Disposal, municipal solid waste, 22.9% water, to sanitary landfill/CH U/AusSD U[12]

[12] The average biogenic component of MSW and C&I wastes is considered to be 50%.

	Item	Amount	Unit	Reference	Background data
	Ferrous and non-ferrous metal recovery	31.7	kg	Primary data, Veolia and EMM Consulting	Modelled based on: Mehr, J., Haupt, M., Skutan, S., Morf, L., Adrianto, L.R., Weibel, G. and Hellweg, S., 2021. The environmental performance of enhanced metal recovery from dry municipal solid waste incinerator bottom ash. Waste management, 119, pp.330-341.

5 Results

5.1 Environmental impact comparison

The LCA results of the energy recovery system are provided in Table 4, Table 5 and Table 6. For each impact category, percentage comparisons with coal-based electricity generation, biomass-based electricity generation and natural gas-based electricity generation are provided in these tables. The key finding is that the proposed model for energy recovery from residual MSW and C&I wastes has lower environmental impacts than electricity production from both coal and biomass for all impact categories. The proposed residual MSW and C&I waste-based electricity production system has also lower environmental impacts than a natural gas-based electricity production system in all environmental impact categories except acidification. In the case of Climate Change, Fossil impact indicator, the proposed residual MSW and C&I waste-based electricity production system performs best against natural gas -based electricity generation system followed by coal-based and biomass-based electricity generation system.

Table 4 - Results of the ARENA commercialisation LCA for generating 1 MWh electricity (considers that residual MSW and C&I wastes are waste products) with the percentage benefit gained/burden added for replacing hard coal by MSW and C&I wastes in power generation.

Impact Category	Measurement unit	1 MWh from MSW and C&I	1 MWh from hard coal	% Benefit gained/ burden added, replacing hard coal by MSW and C&I in power generation
Climate Change, Fossil	kg CO_2 eq	-1,361	898	-166%
Climate Change, Biogenic	kg CO_2 eq	-543	-0.60	N/A–large decrease
Climate Change, Total	kg CO_2 eq	-749	897	-220%
Fossil fuel energy use	MJ NCV	-996	4,629	-565%
Eutrophication	kg PO_4^{---} eq	-3.77	0.124	N/A–large decrease
Particulate matter PM2.5	kg PM2.5 eq	-0.19	0.42	-317%
Consumptive water use	m^3 eq	-64.4	53.3	-183%
Fossil fuel depletion	kg oil eq	-21.83	101.8	-566%
Photochemical oxidation	kg C_2H_4 eq	-0.24	0.080	-132%
Ozone layer depletion (ODP)	kg CFC-11 eq	-4.79E-06	2.90E-06	-161%
Acidification	kg SO_2 eq	0.64	1.94	-204%
Land Use	kg C deficit	-154.6	238.4	-254%

Table 5 - Results of the ARENA commercialisation LCA for generating 1 MWh (considers that residual MSW and C&I wastes are waste products) with the percentage benefit gained/burden added for replacing biomass by MSW and C&I wastes in power generation.

Impact Category	Measurement unit	1 MWh from MSW and C&I	1 MWh from biomass	% Benefit gained/ burden added, replacing biomass by MSW and C&I in power generation
Climate Change, Fossil	kg CO_2 eq	-1361	1,257	-192%
Climate Change, Biogenic	kg CO_2 eq	-543	1,213	-323%
Climate Change, Total	kg CO_2 eq	-749	1,257	-268%
Fossil fuel energy use	MJ NCV	-996	434	-144%
Eutrophication	kg PO_4^{---} eq	-3.77	0.478	N/A–large decrease
Particulate matter PM2.5	kg PM2.5 eq	-0.19	0.18	-194%
Consumptive water use	m^3 eq	-64.40	67.85	-205%
Fossil fuel depletion	kg oil eq	-21.83	9.13	-142%
Photochemical oxidation	kg C_2H_4 eq	-0.24	0.28	-216%
Ozone layer depletion (ODP)	kg CFC-11 eq	-4.79E-06	2.47E-09	N/A–large decrease
Acidification	kg SO_2 eq	0.64	1.93	-203%
Land Use	kg C deficit	-154.6	3,739	N/A–large decrease

Table 6 - Results of the ARENA commercialisation LCA for generating 1 MWh (considers that residual MSW and C&I wastes are waste products) with the percentage benefit gained/burden added for replacing natural gas by MSW and C&I wastes in power generation.

Impact Category	Measurement unit	1 MWh from MSW and C&I	1 MWh from natural gas	% Benefit gained/ burden added, replacing natural gas by MSW and C&I in power generation
Climate Change, Fossil	kg CO_2 eq	-1,361	633	-146%
Climate Change, Biogenic	kg CO_2 eq	-543	0.0100	N/A–large decrease
Climate Change, Total	kg CO_2 eq	-749	633	-184%
Fossil fuel energy use	MJ NCV	-996	10,257	-1130%
Eutrophication	kg PO_4^{---} eq	-3.77	0.056	N/A–large decrease
Particulate matter PM2.5	kg PM2.5 eq	-0.19	0.01	N/A–large decrease
Consumptive water use	m^3 eq	-64.40	4.34	N/A–large decrease
Fossil fuel depletion	kg oil eq	-21.83	225.0	-1131%
Photochemical oxidation	kg C_2H_4 eq	-0.24	0.020	N/A–large decrease
Ozone layer depletion (ODP)	kg CFC-11 eq	-4.79E-06	8.45E-08	N/A–large decrease
Acidification	kg SO_2 eq	0.64	0.21	68%
Land Use	kg C deficit	-154.64	11.08	N/A–large decrease

5.2 Interpretation

Figure 4, Figure 5 and Figure 6 show the benefits gained / burden added for replacing 1 MWh from hard coal-based electricity generation system, 1 MWh biomass-based electricity generation system and 1 MWh natural gas-fired electricity generation system by 1 MWh of residual MSW and C&I waste-based power generation system. The comparisons show that the residual MSW and C&I waste-based power generation system performs better across all environmental impact categories compared to both coal and biomass-based power generation systems. When comparing with natural gas-based power generation system, MSW and C&I waste-based power generation system showed superior performance in all environmental impact categories except acidification.

The biogenic carbon release as well as eutrophication result from coal-based power generation system are not comparable with residual MSW and C&I wastes-based system due to large variation (Table 4). These indicators are excluded in developing Figure 4.

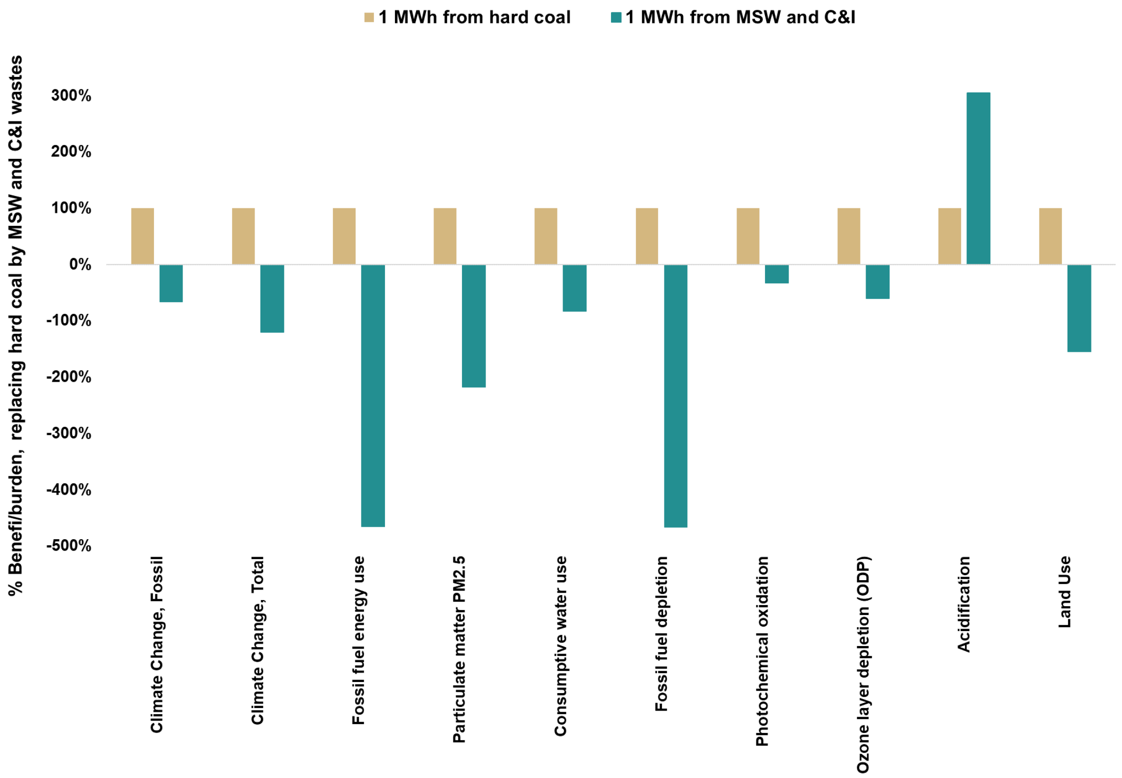

Figure 4 : Disaggregated impacts hot spot analysis - the benefits gained / burden added for replacing 1 MWh from hard coal-based electricity generation by 1 MWh of residual MSW and C&I waste-based power generation.

The eutrophication, ozone layer depletion as well as land use result from biomass-based power generation system are not comparable with residual MSW and C&I wastes-based system due to large variation (Table 5). These indicators are excluded in developing Figure 5.

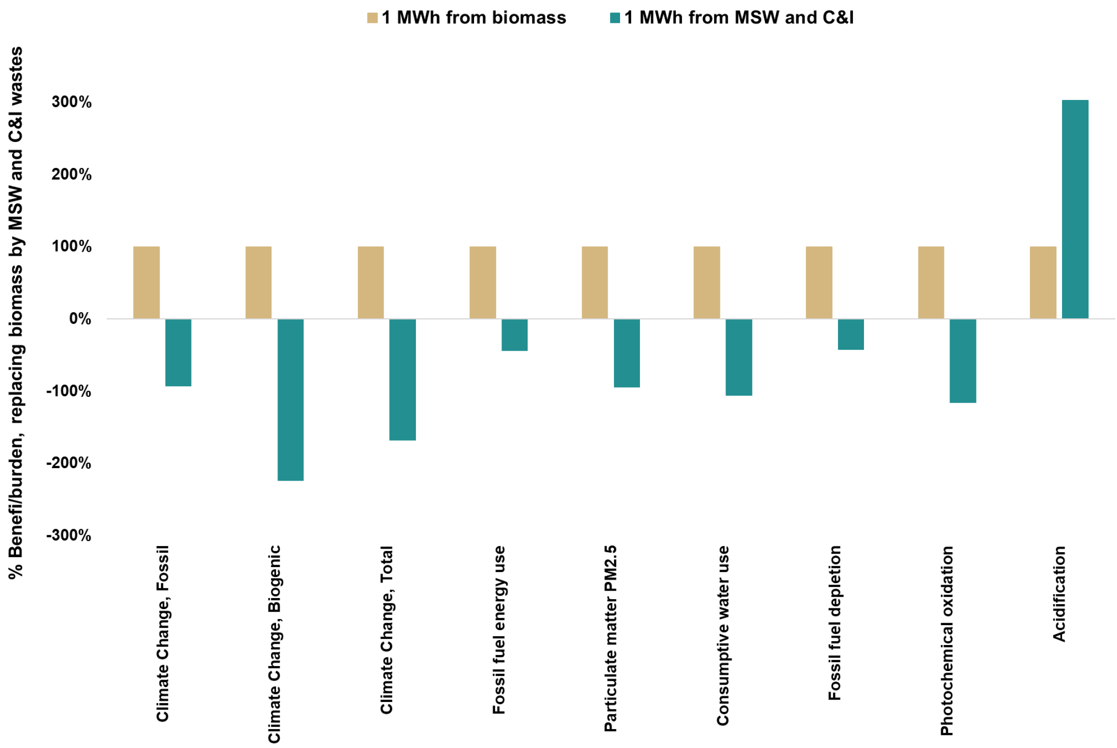

Figure 5 - Disaggregated impacts hot spot analysis - the benefits gained / burden added for replacing 1 MWh from biomass-based electricity generation by 1 MWh of residual MSW and C&I waste-based power generation.

Results of several impact categories such as the biogenic carbon release, eutrophication, particulate matter, consumptive water use, photochemical oxidation, ozone layer depletion as well as land use result from natural gas-based power generation system are not comparable with residual MSW and C&I wastes-based system due to large variation (Table 6). These indicators are excluded in developing Figure 6.

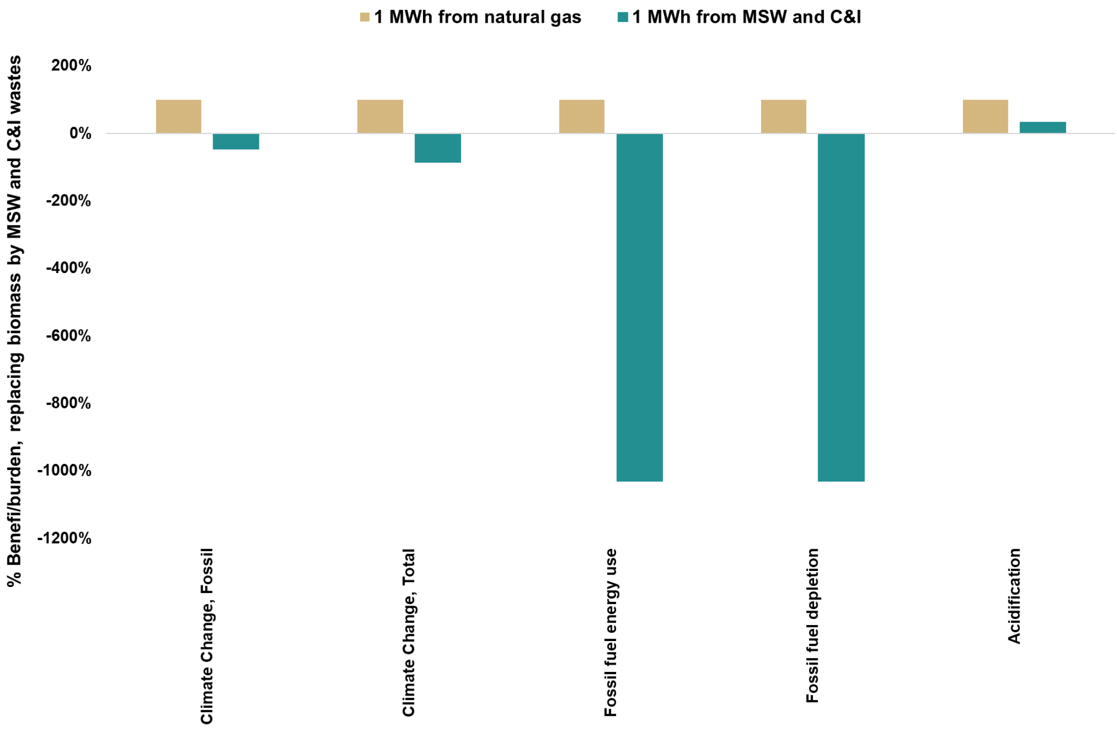

Figure 6 - Disaggregated impacts hot spot analysis - the benefits gained / burden added for replacing 1 MWh from natural gas-based electricity generation by 1 MWh of residual MSW and C&I waste-based power generation.

5.2.1 Total carbon flow

A simple addition of GWP-fossil and GWP-biogenic[13] does not yield GWP-total for bioenergy processes. GWP-fossil of the process accounts the impacts from avoided GHG-fossil as well as avoided GHG-biogenic emissions while GWP-biogenic accounts for impacts from avoided GHG-biogenic emissions. There will be a double counting of avoided GHG-biogenic emissions if GWP-fossil and GWP-biogenic of the process are simply added. The results were manually edited to avoid double counting in this LCA and the results show a 183% reduction in GWP-total emissions. The approach of accounting GWP-fossil in bioenergy processes assists a level playing comparison against other fossil fuel-based power generation system and assists stakeholders in evaluating the actual potential of the project in reducing environmental burdens.

[13] Biogenic carbon: Carbon derived from biomass; Fossil carbon: Carbon which is contained in fossilised material (Edge Environment; Life Cycle Strategies, 2017)

5.3 Annualised results

To allow for a comparison of the Woodlawn ARC project with similar projects, the LCA results have been presented in annualised formats in Table 7, Table 8 and Table 9. These results are based on an estimated annual electricity generation of up to 240,000 MWh per year. Accounting for parasitic loss, the exportable electricity is expected to be up to 219,830 MWh per annum. In the case of Climate Change, Total, the results were manually edited to avoid double counting as described in 5.2.1.

Table 7 – Annualised results of LCA study (assumes an annual electricity generation of up to 240,000 MWh) with a comparison against **coal-based electricity production**.

Impact Category	Measurement unit	Annual impact - MSW and C&I	Annual impact – hard coal	Annual variation, by replacing hard coal by MSW and C&I in power generation
Climate Change, Fossil	kg CO_2 eq	-326,552,301	215,478,511	-542,030,813
Climate Change, Biogenic	kg CO_2 eq	-130,255,974	-144,270	-130,111,704
Climate Change, Total	kg CO_2 eq	-179,699,495	215,334,241	-395,033,736
Fossil fuel energy use	MJ NCV	-239,040,456	1,111,062,864	-1,350,103,320
Eutrophication	kg PO_4^{---} eq	-903,927	29,813	-933,740
Particulate matter PM2.5	kg PM2.5 eq	-46,121	100,259	-146,380
Consumptive water use	m^3 eq	-15,456,425	12,785,336	-28,241,761
Fossil fuel depletion	kg oil eq	-5,239,760	24,438,545	-29,678,305
Photochemical oxidation	kg C_2H_4 eq	-58,087	18,786	-76,874
Ozone layer depletion (ODP)	kg CFC-11 eq	-1.15	0.70	-1.85
Acidification	kg SO_2 eq	153,241	466,167	-312,926
Land Use	kg C deficit	-37,112,833	57,211,714	-94,324,547

Table 8 - Annualised results of LCA study (assumes an annual electricity generation of up to 240,000 MWh) with a comparison against **biomass-based electricity production**.

Impact Category	Measurement unit	Annual impact - MSW and C&I	Annual impact - biomass	Annual variation, by replacing biomass by MSW and C&I in power generation
Climate Change, Fossil	kg CO_2 eq	-326,552,301	310,710,686	-628,262,987
Climate Change, Biogenic	kg CO_2 eq	-130,255,974	291,031,416	-421,287,390
Climate Change, Total	kg CO_2 eq	-179,699,495	301,710,686	-481,410,180
Fossil fuel energy use	MJ NCV	-239,040,456	104,149,452	-343,189,908
Eutrophication	kg PO_4^{---} eq	-903,927	114,704	-1,018,631
Particulate matter PM2.5	kg PM2.5 eq	-46,121	43,498	-89,619
Consumptive water use	m^3 eq	-15,456,425	16,284,419	-31,740,844
Fossil fuel depletion	kg oil eq	-5,239,760	2,190,196	-7,429,957
Photochemical oxidation	kg C_2H_4 eq	-58,087	67,289	-125,377
Ozone layer depletion (ODP)	kg CFC-11 eq	-1.15E+00	5.93E-04	-1.15E+00
Acidification	kg SO_2 eq	153,241	463,937	-310,696
Land Use	kg C deficit	-37,112,833	897,365,328	-934,478,161

Table 9 - Annualised results of LCA study (assumes an annual electricity generation of up to 240,000 MWh) with a comparison against **natural gas-based electricity production**.

Impact Category	Measurement unit	Annual impact - MSW and C&I	Annual impact - natural gas	Annual variation, by replacing natural gas by MSW and C&I in power generation
Climate Change, Fossil	kg CO_2 eq	-326,552,301	151,804,637	-478,356,938
Climate Change, Biogenic	kg CO_2 eq	-130,255,974	1,887	-130,257,861
Climate Change, Total	kg CO_2 eq	-179,699,495	151,806,524	-331,506,018
Fossil fuel energy use	MJ NCV	-239,040,456	2,461,585,200	-2,700,625,656
Eutrophication	kg PO_4^{---} eq	-903,927	13,328	-917,255
Particulate matter PM2.5	kg PM2.5 eq	-46,121	2,856	-48,977
Consumptive water use	m^3 eq	-15,456,425	1,042,443	-16,498,868
Fossil fuel depletion	kg oil eq	-5,239,760	54,006,794	-59,246,555
Photochemical oxidation	kg C_2H_4 eq	-58,087	4,931	-63,018
Ozone layer depletion (ODP)	kg CFC-11 eq	-1.15	0.0200	-1.17
Acidification	kg SO_2 eq	153,241	49,556	103,685
Land Use	kg C deficit	-37,112,833	2,659,326	-39,772,159

5.4 Hotspot analysis for environmental impacts

Hotspot analysis is widely used terminology in LCA and is employed to gain an understanding of where the environmental impacts of a product or process are concentrated.

This analysis was performed to systematically evaluate the environmental impacts of Woodlawn ARC's energy from waste process. The results indicate that the environmental impact hotspots are primarily based in the process for electricity production from thermal treatment of residual MSW and C&I waste (Table 10, refer to red shaded cells for key sources of impact).

Table 10 – 1 MWh of electricity using residual MSW and C&I waste – disaggregated impacts hot spot analysis.

Highest impact ⟶ Lowest impact

Impact Category	Unit	Sorting MSW and C&I waste	Waste transport to Woodlawn ARC	Infrastructure (dedicated road)	Electricity from the thermal treatment of MSW and C&I waste	IBA and APCr landfill
Climate Change, Fossil	kg CO_2 eq	1.15E+01	1.96E+01	1.18E-01	2.96E+01	3.57E+00
Climate Change, Biogenic	kg CO_2 eq	1.94E-02	9.10E-03	4.45E-04	6.12E+02	7.37E-04
Climate Change, Total	kg CO_2 eq	1.15E+01	1.96E+01	1.18E-01	6.42E+02	3.57E+00
Fossil fuel energy use	MJ NCV	8.76E+01	2.12E+02	2.06E+00	2.22E+02	1.04E+02
Eutrophication	kg PO_4^{---} eq	8.51E-03	2.36E-02	2.03E-04	2.17E-01	1.94E-01
Particulate matter PM2.5	kg PM2.5 eq	9.92E-03	1.78E-02	2.17E-04	8.02E-02	2.54E-03
Consumptive water use	m^3 eq	1.02E+00	1.07E+01	8.08E-04	4.65E+01	8.18E-01
Fossil fuel depletion	kg oil eq	1.93E+00	4.63E+00	4.49E-02	4.86E+00	2.26E+00
Photochemical oxidation	kg C_2H_4 eq	1.04E-03	3.41E-03	2.37E-05	1.60E-02	7.14E-04
Ozone layer depletion (ODP)	kg CFC-11 eq	1.54E-08	1.58E-06	1.62E-08	1.20E-06	1.14E-06
Acidification	kg SO_2 eq	3.29E-02	9.84E-02	5.98E-04	1.13E+00	1.03E-02
Land Use	kg C deficit	1.48E+00	7.64E+01	1.05E+00	1.04E+01	1.06E+02

The avoided impact from landfill of residual MSW and C&I wastes as well as the recycling benefits of ferrous and non-ferrous metals are not shown in Table 10. The avoided impact from landfill of residual MSW and C&I wastes contributes a biogenic carbon benefit to the residual MSW and C&I wastes-based power generation system. This is due to the avoidance of biogenic methane, which is a result of landfilling organic matter, i.e., the anaerobic decomposition of MSW and C&I wastes organic matter in landfill. The recycling of ferrous and non-ferrous metals (recovered from IBA) reduces the use of natural resources and provides environmental benefits.

5.5 Sensitivity analysis

The sensitivity of diesel consumption in sorting of MSW and C&I wastes at the waste transfer stations was performed. In waste collection, diesel use in sorting is one of the most uncertain inventories. A previous work at the Technical University of Denmark suggests that the diesel consumption in sorting facility can very from 1.4 – 10.1 litre per tonne of waste (Larsen, Vrgoc, Christensen, & Lieberknecht, 2009). In this LCA, the diesel usage for the sorting of MSW and C&I wastes was varied between 1.5 and 3.0 times of baseline value. The results of the sensitivity analysis are provided in Table 11. The environmental impacts are found to be increased up to 1.3% except acidification. The acidification value is sensitive to diesel consumption and the variation was between 1.6 and 6.4%.

Table 11 – Sensitivity of life cycle impact assessment results for generating 1 MWh from baseline to increased usage of diesel in sorting of residual MSW & C&I wastes

Impact Category	Unit	1.5 times of baseline diesel consumption	2 times of baseline diesel consumption	3 times of baseline diesel consumption
Climate Change, Fossil	kg CO_2 eq	0.13%	0.25%	0.50%
Climate Change, Biogenic	kg CO_2 eq	0.00%	0.00%	0.00%
Fossil fuel energy use	MJ NCV	0.06%	0.13%	0.26%
Eutrophication	kg PO^{4---} eq	0.06%	0.12%	0.24%
Particulate matter PM2.5	kg PM 2.5 eq	0.32%	0.63%	1.26%
Consumptive water use	m^3 eq	0.03%	0.06%	0.13%
Fossil fuel depletion	kg oil eq	0.06%	0.13%	0.26%
Photochemical oxidation	kg C_2H_4 eq	0.16%	0.32%	0.63%
Ozone layer depletion (ODP)	kg CFC-11 eq	0.00%	0.01%	0.02%
Acidification	kg SO_2 eq	1.69%	3.38%	6.76%
Land Use	kg C deficit	0.01%	0.01%	0.03%

6 Conclusion and recommendations

The Woodlawn Advanced Energy Recovery Centre (ARC) project is expected to generate up to 240,000 megawatt hours (MWh) of electricity per annum from the thermal treatment of residual MSW and C&I wastes up to 380,000 tonnes per annum. Accounting for parasitic loss, the exportable electricity is expected to be up to 219,830 MWh per annum. The project is classified as a State significant development (SSD) under the Environmental Planning and Assessment Act 1979 (EP&A Act) in accordance with Schedule 1 of State Environmental Planning Policy (Planning Systems) 2021 (PS SEPP).

This report fulfils the requirement of the SEARs to prepare a commercialisation LCA that is in line with the ARENA Method. The results of the LCA show that the residual MSW and C&I waste-based power generation system performs better across all environmental impact categories compared to both coal and biomass-based power generation systems. When comparing with natural gas-based power generation system, residual MSW and C&I waste-based power generation system showed superior performance in all environmental impact categories except acidification.

The residual MSW and C&I waste-based power generation system results in 183% emissions reduction (GHG-total) compared to coal-based power generation system. When compared to biomass-based and natural gas-based electricity generation, the emissions reduction (GHG-total) values are 160% and 218%, respectively. This reduction is primarily due to avoided landfilling of residual MSW and C&I wastes. The predicted annual GWP-total saving from the Woodlawn ARC project is 395,034 tonnes of CO_2 eq. when compared to electricity production using hard coal. When compared to biomass-based and natural gas-based electricity generation, the annual GWP-total saving is 481,410 and 331,506 tonnes of CO_2 eq., respectively. The results indicate that the environmental impact hotspots are primarily based in the process for electricity production from thermal treatment of residual MSW and C&I wastes.

The following recommendations are made to further reduce the environmental impact of residual MSW and C&I waste -based power generation system:

- Revisit LCA analysis with refined and updated primary data. Residual MSW and C&I wastes requirement per MWh production as well as water consumption and ash disposal data (particularly the beneficial use of it as a substitute for virgin material) may require more attention for future analysis.
- Explore use of renewable energy for sorting and power generation systems at the waste transfer stations.

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Appendix A: Annual air emissions from the ARC stack

Table A1 is used in the LCA of electricity production at the ARC using residual MSW and C&I wastes. This data is sourced from EMM Consulting and is based on modelling of the facility.

Table A1 – Annual air emissions from ARC stack (for the production of 240,000 MWh)

Pollutant	ARC stack - annual emissions (tpa)
Particles (as PM2.5)	1.00E-01
Type 1&2 substances	4.00E-02
Mercury	2.60E-03
Cadmium and Thallium	2.69E-03
Dioxins and Furans	3.72E-08
Sulphur Dioxide	5.42E+01
Oxides of nitrogen	3.45E+02
Carbon Monoxide	5.72E+00
Hydrogen chloride	1.52E+01
Hydrogen fluoride	5.65E-02
VOCs	3.50E-01
Ammonia	9.82E+00
PAHs	9.33E-04
Antimony	3.31E-03
Arsenic	1.15E-03
Beryllium	1.09E-05
Cadmium	1.44E-03
Chromium	5.79E-03
Cobalt	1.15E-03
Copper	8.02E-03
Lead	5.96E-03
Manganese	7.07E-03
Mercury	2.60E-03
Nickel	8.97E-03
Thallium	1.25E-03
Vanadium	1.58E-03
Zinc	1.02E-02
PCB	8.63E-09
CO_2, biogenic	1.47E+05

Appendix B: Critical Review

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To whom it may concern,

Monday, 18th July 2022

RE: Veolia Woodlawn Advanced Energy Recovery Facility Commercialisation LCA Report – Peer Review

This critical review of the *Commercialisation LCA* regarding the environmental effects from the proposed *Woodlawn Advanced Energy Recovery Centre (ARC) Project*, was carried out by Jonas Bengtsson, Edge Environment, after the international standard ISO 14044 and the standards set by ARENA as closely as possible.

The review was carried out in July 2022. The overall finding of the review is that the study lives up to the ISO standards and guidelines for LCA. There are minor areas where the reporting can be improved, but the reviewer does not find this will change the overall findings. Most of the choices with regards to data taken for the modelling of the project are conservative, which indicate that value-choices in the LCA have been cautious, and if anything the results could favour the waste to energy recovery more than indicated.

The final checklist and comments are included in the table below.

Sincerely,

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Standard Reference	Review Comments / Check
Goal and Scope Definition	
Goal of the study	It follows the ARENA guidelines.
Functional Unit	It follows the ARENA guidelines.
System Boundary	It follows the ARENA guidelines.
System Description	It follows the ARENA guidelines.
Temporal Coverage	It follows the ARENA guidelines.
Technology Coverage	It follows the ARENA guidelines.
Geographical Coverage	It follows the ARENA guidelines.
Cut off Criteria	It follows the ARENA guidelines.
LCIA methodology and types of impacts;	It follows the ARENA guidelines.
Data Quality Requirements	It follows the ARENA guidelines.
Life Cycle Inventory	
Data Collection Procedures and Sources	√
Data Calculation Information	√
Missing Data	√
Allocation Rules	It follows the ARENA guidelines.
Life Cycle Impact Assessment	
Characterisation Models	It follows the ARENA guidelines.
Description of Impacts	√
Appropriateness of Selected Impacts and Models	It follows the ARENA guidelines.
Normalisation and Weighting	N/A
Comparative Assertions made Public – Appropriateness of LCIA	It follows the ARENA guidelines.
Limitations and Exclusions	√
Interpretation	
Reveiwers Check of Results against Comparable Studies	The results are reasonable in comparison against comparable studies, noting some discrepancies compared to other ARENA waste to energy LCA reports in terms of emission factors used for avoided landfill emissions. Also noting that other studies using raw MSW and D&D waste obtains a higher avoided landfill emission profile that the smaller avoided impact from RDF.
Consistency with Goal and Scope of Study	√
Documentation of Data Quality Checks	√
Identification and Explanation of Significant Issues	√
Evaluation - Sensitivity Analysis	√
Conclusions	√
Reporting	
Executive summary	√
General	√