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RELIABLE AFFORDABLE CLEAN ENERGY

B5 Research Project

Mapping Organic Waste in Sydney: Advancing Anaerobic Co-Digestion

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Mapping Organic Waste in Sydney: Advancing Anaerobic Co-Digestion

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Project team

University of Technology Sydney

- A. Turner
- M. Jazbec
- B. Madden
- D.L. Nghiem

Project partners

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Although the IRG members and partners have provided valuable inputs and feedback throughout the project, the findings and recommendation included in this report do not necessarily reflect the views of each individual member.

Acknowledgement of Country

The authors of this report would like to respectfully acknowledge the Traditional Owners of the ancestral lands throughout Australia and their connection to land, sea and community. We recognise their continuing connection to the land, waters and culture and pay our respects to them, their cultures and to their Elders past, present, and emerging.

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Executive Summary

The energy, water and waste sectors share a common policy objective of achieving net-zero emissions by 2050 and a commitment to the Global Methane Pledge of cutting at least 30% of anthropogenic methane emissions by 2030 from 2020 levels. This study investigates steps towards achieving these objectives. It does so by bringing together the siloed energy, water and waste sectors and exploring the opportunity of co-digestion of urban organic waste at wastewater treatment plants (WWTP) to generate bioenergy. It also highlights multiple other potential cross-sectoral sustainability benefits from landfill diversion to knowledge sharing.

Co-digestion of urban organic wastes at WWTPs is an opportunity for waste diversion from landfill

In the study three Sydney Water WWTPs (Malabar, St Marys and Riverstone) are used to illustrate landfill diversion opportunities for the urban organic wastes generated in the adjacent local government areas of Penrith, Blacktown, Randwick and Bayside. The investigations show significant untapped potential of using anaerobic digestion (AD) for the generation of biogas from urban organic wastes such as food waste and fats, oils and grease from grease traps. The AD process, which aligns with circular economy principles, helps reduce the greenhouse gas emissions footprint for urban organic waste. In addition, it generates a beneficial by-product, digestate, which contains soil enriching nutrients. Processing urban organic waste at WWTPs also offers a pragmatic and expedited solution to the strategic targets for waste diversion from landfills due to the established AD infrastructure and extensive knowledge based at WWTPs. The three selected WWTPs could provide as much as 20% of the identified AD infrastructure capacity gap needed for Sydney by 2030, e.g., over 50 kt/y capacity, equivalent to the capacity at EarthPower, the only commercial AD plant in Sydney.

WWTPs as circular economy hubs

Co-digestion of sewage utilising urban organic waste streams also benefits WWTPs, as it enhances biogas and energy generation. Several WWTPs around the world have achieved energy self-sufficiency and even surplus through co-digestion of sewage with external organic waste feedstocks. This enables WWTPs to evolve into circular economy hubs as they become a source of renewable energy and supplier of soil conditioner for the communities and businesses providing organic waste. Such hubs are continuing to evolve by exploring opportunities to manufacture bio-based materials such as bioplastics from organic wastes.

Bringing energy, water and waste sectors together to share data & knowledge

To avoid locking in solutions that reduce cross-sectoral collaboration and the opportunity to transition to a circular economy, careful decision-making processes are required. As part of the study investigations, a methodology and framework have been developed for estimating and mapping available organic resources for potential co-digestion of various streams from both the residential and non-residential sectors. The investigations address data paucity and reliability, suitability of feedstocks for co-digestion and required collection methods. The pooling of data on the geospatial and sectoral distribution of urban organic wastes along with their energy potential, using hot-spot maps illustrated in this study, could provide invaluable input to aid in cross-sectoral solutions investigations and associated decision-making. Initial stakeholder mapping, conducted as part of the study, illustrates the complexity of different interests and regulatory barriers that need to be considered. This could also provide important input to future cross-sectoral urban organic waste investigations and decision-making at this critical juncture.

The following infographic provides a summary of organic waste resources available for co-digestion and their distribution between residential and non-residential sectors along with the benefits for the selected WWTPs and the adjacent local government areas.

18% of Greater Sydney population **930,196**

32,156 businesses | 330,112 employees

62% are single unit 191,959 dwellings

38% are multi unit 116,635 dwellings

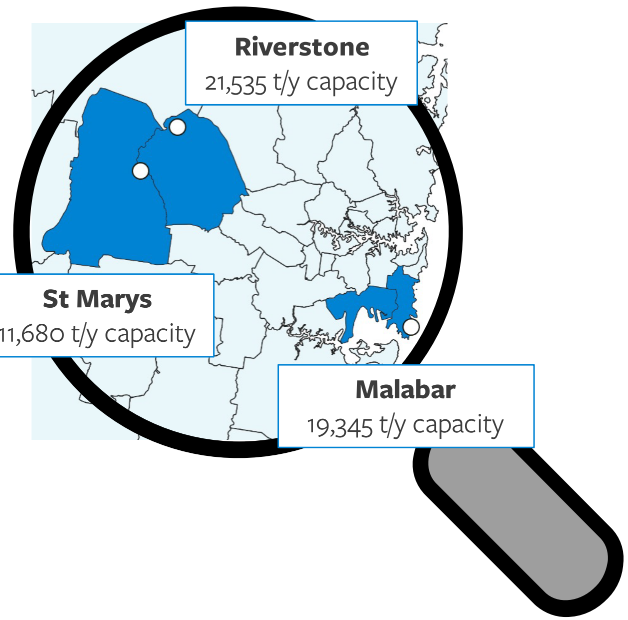
ORGANIC RESOURCES available for co-digestion

NON-RESIDENTIAL	RESIDENTIAL		
40,000 tonnes of **food waste**	69%	68,000 tonnes of **food waste**	31%
32,000 tonnes of **garden organics**	78%	77,000 tonnes of **garden organics**	22%
12 gigalitres of **sewage**	71%	46 gigalitres of **sewage**	29%
3.2 million litres of **fats oils and grease**			

The three selected WWTPs could fill as much as 20% of the identified Sydney 2030 AD infrastructure **capacity** gap - 52,560 t/y.

BENEFITS

- 37.8 billion litres of **biogas** for renewable energy
- 33,000 tonnes per year of **CO2e** avoided
- 9,600 tonnes of **biosolids** for soil enrichment



Glossary

ABBA	Australian biomass for bioenergy assessment project
ABS	Australian Bureau of Statistics
AD	Anaerobic digestion
ANZSIC	Australian and New Zealand Standard Industrial Classification
AORA	Australian Organics Recycling Association Limited
APCO	Australian Packaging Covenant Organisation
ARENA	Australian Renewable Energy Agency
AWT	Alternative waste treatment
C	Carbon
CE	Circular economy
CH_4	Methane
C&I	Commercial and industrial
CO_2	Carbon dioxide
CO_2-e	Carbon dioxide equivalent
CRC	Cooperative research centre
FIAL	Food Innovation Australia Limited, the food and agribusiness growth centre
FO	Food organics
FOG	Fats oils and grease
FOGO	Food organics garden organics
GHG	Greenhouse gas
GO	Garden organics
GSC	Greater Sydney Commission
GSP	Gross State Product
GWP	Global warming potential
HH	Household
IRG	Industry reference group
K	Potassium
LGA	Local Government area
MBT	Material biological treatment
MSW	Municipal solid waste
MUD	Multi-unit dwelling
N	Nitrogen
OEH	Environment and heritage
P	Phosphorus
pH	A measure how acidic/basic is.
ROC	Regional organisation of councils
SA1	Statistical area 1
SSROC	Sydney regional organisation of councils
SUD	Single unit dwelling
UCO	Used cooking oil
UOW	Urban organic waste
WARR	Waste avoidance and resource recovery
WCRA	Waste Contractors and Recyclers Association
WMRR	Waste Management and Resource Recovery Association
WWTP	Wastewater treatment plant

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1 Introduction

Greenhouse gas (GHG) emissions reported as arising from the 'waste sector' account for 2.7% of national GHG emissions (DCCEEW, 2022a). These emissions account for emissions from landfill, wastewater treatment and some waste processing[1], e.g., waste incineration and the biological treatment of solid waste. The vast majority of the reported waste sector emissions come from solid waste disposal (75%), and the associated methane generated from anaerobic decomposition of organic matter in landfills (DCCEEW, 2022a). Almost half of all core organic waste generated in Australia and managed by the waste sector (e.g., excluding the non-core waste from the agricultural sector) is disposed to landfill with only a small proportion (8%) of the methane generated in landfills captured as landfill gas for energy generation (Pickin, et al., 2020). Such a significant quantum of organic waste passing to landfill presents opportunities to minimise organic waste generation in the first place, but also provides opportunities to avoid disposal of organic waste to landfill and via various processes capture the methane as a renewable energy resource.

Diversion of organic waste from landfill requires expansion of the current organics waste collection and processing services in both the residential and non-residential sectors. Recently, the NSW Government identified a 1.1 million tonnes per year (t/y) processing capacity gap for food and garden organics waste in NSW, as part of the 2021 Guide to future infrastructure needs (DPIE, 2021b), to help meet the NSW Waste and Sustainable Materials Strategy objectives (DPIE, 2021a). To service just the Greater Sydney region's demand by 2030, an additional four large anaerobic digestors (AD) with a capacity of 50,000 t/y and two medium ADs with a capacity of 30,000 t/y will be required along with other large and smaller scale organics infrastructure and processing; including dedicated organic waste transfer stations, and 'dirty' material recycling facilities[2] (DPIE, 2021b).

Most Australian states have made commitments to halve the disposal of organic waste to landfill by 2030, and to the net zero GHG emissions target by 2050 (See Appendix Table 5). Australia has also recently signed the Global Methane Pledge to reduce global methane emissions across all sectors by at least 30% below 2020 levels by 2030 (DCCEEW, 2022b). Diverting organic waste from landfill by processing it through anaerobic digestion (AD) aligns well with these strategic directions and provides significant potential not yet tapped into, with currently only 2% of organic waste in Australia processed via AD (DCCEEW, 2022a) significantly lower than many comparable countries for various complex reasons (Jain, 2019 and IEA Bioenergy, 2022). In 2020, just 5% of the total clean electricity, or 1.4% of total electricity, was generated from bioenergy, of which sugar cane waste from the agricultural sector and landfill gas from the waste sector were the main fuel sources (CEC, 2020). Various studies have identified the potential for biogas in Australia, estimating that, according to 2019 figures, biogas could supply 9% of current total Australian energy consumption needs (Carlu, et al., 2019, DEE, 2018 and Kaparaju, et al., 2023). Assuming that consumption of gas remained the same, 33% of the gas could be supplied from biogas[3].

[1] These emissions do not account for the emissions upstream associated with the generation, waste treatment or transport of the waste for treatment and disposal which can be significant.

[2] Alternative waste treatment (AWT) facilities process mixed solid waste that would have gone to landfill into products such as compost, fuel or biogas, as well as recovery of plastics, glass and metals. The organic product often has a high contamination level limiting it application, especially as soil conditioner, and is therefore sent to landfill, open cut mine remediation or used in roads, after material biological treatment (MBT) has extracted energy.

[3] Estimated based on the reported data in the Australian Energy Updated for 2022 (Commonwealth of Australia, 2022).

The other main source of GHG emissions from the Australian waste sector (23%) arises from wastewater treatment (DCCEEW, 2022a). Whilst the carbon footprint of wastewater treatment has been decreasing over the past three decades, this has been mainly due to methane capture and flaring. Installation of AD as a part of wastewater treatment could enable mitigation of the remaining 44% GHG emissions identified (DCCEEW, 2022a). While water utilities in Australia are adding AD to their wastewater treatment plant (WWTP) processes and planning for population growth, there is potential additional AD capacity emerging. This emerging capacity will provide an opportunity for the WWTPs to accept external (non-sewage) organic feedstock to be co-digested via their existing and new ADs. Co-digestion of sewage with other types of organic feedstock such as food waste organics (FO) and fats oils and grease (FOG) from grease traps offers significant potential benefits. These benefits include, for example, the potential for: increased generation of biogas due to improved operational characteristics with the addition of FO to the sewage influent; cross sectoral alignment of GHG and net zero policy objectives; and savings on the capital expenditure required for new AD infrastructure needed for processing of urban organic waste (UOW) in major cities such as Sydney.

The core aim of this study is to identify the energy potential from UOW that could be co-digested at WWTP AD. The study focuses specifically on three Sydney Water WWTPs (Malabar, St Mary's and Riverstone) and urban organic feedstocks from the adjacent local government areas (LGAs) of Penrith, Blacktown, Randwick and Bayside as illustrative case study areas. The study aims to bring together the typically siloed waste, wastewater and energy sectors to assist in investigating the opportunities of urban bioenergy potential and meeting emerging cross-sectoral policy objectives. It identifies and maps the estimated available UOW resources in the focused case study areas. It provides an assessment of potential bioenergy generation for the UOW resources and identifies hot-spots based on the intensity of potential bioenergy. It also identifies avoided GHG emissions and potential benefits of the biosolids that are generated from the AD process. Relevant and often disparate stakeholders that need to be involved along the organics value chain are identified and mapped. The study also provides an analysis framework for potential future work that could expand the scope of analysis to the Greater Sydney area and/or other jurisdictions and summarises overall study findings and recommendations to assist in much needed cross sectoral knowledge sharing.

1.1 Urban organic waste systems

UOW is present across multiple sectors (residential and non-residential including commercial & industrial businesses and institutional establishments) and across multiple streams that are managed (collected and processed) in various ways. It forms a complex system involving a mix of stakeholders (private and government) both generating and managing that waste. Table 1 summarises the main UOW streams, their definitions, in which sectors they are generated and common processing options.

Table 1: Urban organic waste – definition, its occurrence and processing options.

UOW streams	Definition	Generation in sectors			Processing options
		Residential	Commercial & Industrial	Institutional	
Food waste (FO)	Solid or liquid food intended for human consumption not reaching consumer or reaching consumer but thrown away.	Y	Y	Y	• composting • vermi-composting • AD with energy recovery • protein farming using insects' larvae • landfill
Garden organics (GO)	Organic waste from gardening or landscaping activities including grass cuttings, leaves, branches.	Y	Y	Y	• composting • combustion • hydrolysis • landfill
Sewage	Wastewater and excrement conveyed in sewers for local or centralised treatment.	Y	Y	Y	• aerobic digestion • AD • AD with energy recovery
Used cooking oil (UCO)	Oils and fats that have been used for cooking or frying.	Y	Y	Y	• biodiesel production • landfill • AD with energy recovery
Fats, oils and grease (FOG)	Non-petroleum organic polar compounds derived from animal or plant sources containing carbon chain triglyceride molecules.		Y	Y	• soil injection • AD with energy recovery
Trade waste	Non-human waste generated on commercial and industrial properties that is discharged to sewage system under licence with the local council/utility or collected and treated by a licenced waste management company.		Y		• aerobic digestion • AD • AD with energy recovery
Pet waste	Faeces or faeces contaminated material such as kitty litter or woodchips from any household pet but does not include animal carcasses or parts.	Y	Y	Y	• landfill • special separate composting

In Australia, the development of national strategies and policies for management of waste have historically been strongly guided by the waste hierarchy (NSW EPA, 2022c) which lists the order of preference in management of wastes (Appendix Figure 31). The waste hierarchy prioritises minimisation of waste generation through waste prevention, reuse and repurposing. The next priority focuses on recycling as much as possible from the waste that is unavoidably generated, by capturing energy and secondary materials for recycling. In the last option the remaining residual waste, after all higher priorities in the waste hierarchy have been exhausted, is landfilled.

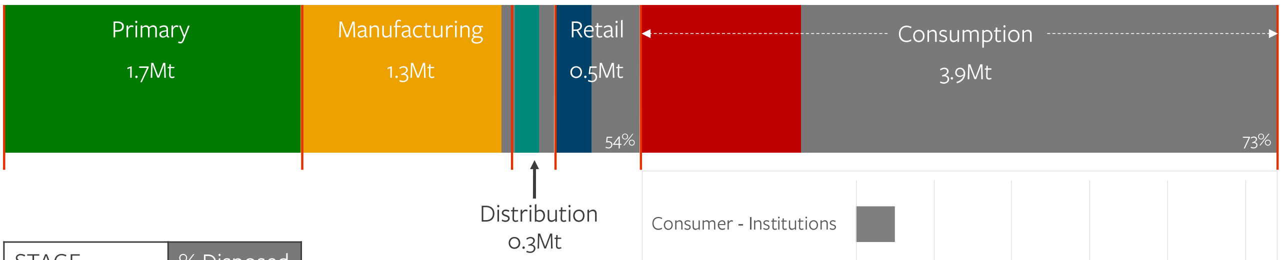
However, in the circular economy, organic waste is highly valued and should not be landfilled but the resource recovered for multiple beneficial uses (Zero Waste Europe, 2019 and Turner, et al., 2019). In a circular economy, after energy is recovered through AD, gasification, pyrolysis or combustion processes (which is used for generation of electricity, heat or fuel), the residual organic waste should form a resource for organic soil improvers, fertilisers or other bio-based products. Yet, 44% of organic waste (including FO, GO, timber and biosolids) generated in Australia is disposed to landfill (Pickin, et al., 2020), and is thus unsustainable in relation to the circular economy principles, net zero and waste management targets (Appendix Table 5).

Multiple UOW streams disposed to landfill are suitable for AD with energy recovery (Table 1). However, currently there is only one commercial AD plant in Sydney (accepting FO and FOG from UOW and predominantly from the non-residential streams) with a capacity of 52,000 t/y (EarthPower, 2022). Considering the population growth and diversion of organics from landfill targets, the NSW Government has identified a processing gap of 1,100,000 t/y for organic waste in NSW, including Greater Sydney UOW. To service Greater Sydney needs alone, the infrastructure strategy estimates that an additional 740,000 t/y of composting and 260,000 t/y of AD infrastructure capacity will be required by 2030 (DPIE, 2021).

The NSW Waste and Sustainable Materials Strategy 2041 (DPIE, 2021a) specifically states that a separate collection of food and garden organics from all NSW households will be required by 2030. All but four Greater Sydney councils already offer GO collection (Appendix Section A.3). Two councils offer a combined food organics and garden organics (FOGO) bin service and one council a separate food waste collection (FO) service for apartments. Another three councils are currently performing a separate FO trial for apartments. In addition, many councils have opted to support composting of FO at home by subsidising the purchase of low-cost equipment and providing education. Therefore, some of the households already compost at home. In Australia it has been estimated that 18% of FO was composted at home in 2020 (FIAL, 2021). The vast majority of FO generated by residential households in Australia is thus disposed to landfill (73%) as shown in Figure 1.

The NSW Waste and Sustainable Material Strategy 2041 (DPIE, 2021a) also states that separate collection of FO from targeted businesses and other entities that generate the highest volumes of FO, including large supermarkets and hospitality businesses, will require separate FO collection, whilst only 3% was collected for commercial composting (FIAL, 2021). Hence, again as in the residential sector, in 2020, the vast majority of FO generated from the hospitality sector across Australia (68%) was disposed to landfill (Figure 1).

These key strategic objectives in NSW, which are mirrored in many other states across Australia, aim to address the significant quantum of FO generated at the consumer stage of the supply chain that is currently predominantly disposed to landfill, that is, from the institution, hospitality and household sub-sectors as shown in Figure 1 (FIAL, 2021).



STAGE	% Disposed to landfill
Primary	0%
Manufacturing	6%
Distribution	35%
Retail	54%
Consumption	73%

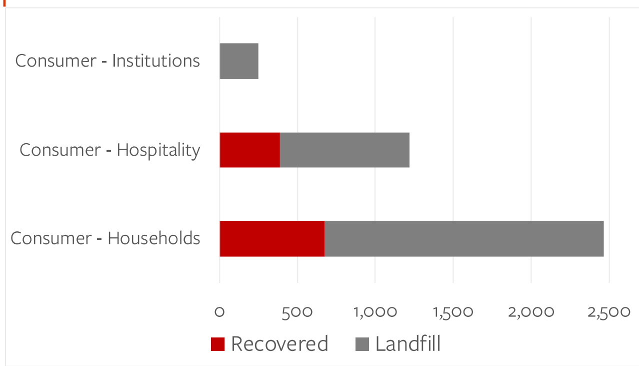


Figure 1: Generation of FO along the supply chain (Mt/y) in Australia, including % of landfill. Consumer FO generation breakdown by sector (Mt/y) and destination (FIAL, 2021).

Although in Australia FO occurs along the whole supply chain, the consumer stage is responsible for half of the FO generated and the largest proportion of FO disposed to landfill (Figure 1). Most of the FO generated in the primary and manufacturing stages of the supply chain is recovered on farm or through industrial composting. Only 6% of FO is disposed to landfill from the manufacturing sector but almost half of the FO generated during the distribution and retail stages is still disposed to landfill (FIAL, 2021). Source separated FO from the latter stages of the supply chain (e.g., distribution and retail as well as the consumer stage) therefore provides a particularly valuable feedstock opportunity for landfill avoidance and AD bioenergy generation potential.

When FO is collected from businesses and separated to residual waste bins, it is generally collected as a separate stream for processing. However, in Australia the residential sector has taken a unique approach of collecting FO with GO (e.g., FOGO). The basis for this approach is mainly attributed to the fact that many councils currently already offer GO collection services (Appendix Section A.3). Hence to avoid the need for an additional bin to collect the relatively small amount of FO generated by each household, Australia has taken an approach of combining the FO with the GO stream. In addition, due to the established management of GO through composting, it has generally been assumed that the majority of FO would be composted with GO. However, combining the two streams together eliminates (or complicates) an opportunity to capture the biogas through the AD process due to the requirement of an expensive pre-treatment and/or reactor configuration, product quality, as well post digestion treatment requirements (Steffen, et al., 1998). Considering 54% of FO disposed to landfill in Australia is from households (FIAL, 2021), this means that half of the potential feedstock for AD to generate biogas would be lost (or significantly complicated) due to collection via FOGO. However, as noted earlier, several urban councils in Sydney are trialling separate FO collection for apartments, which tend to generate only a small amount of GO. Due to their density and the fact they are a significant growth sector, collection from such apartments potentially represents a more economically attractive option for a separate FO collection service that could be directed to AD treatment.

Internationally, combined residential and non-residential, door-to-door FO collection and subsequent processing via AD is considered best practice (Wanderley, et al., 2022). This firstly enables extraction of biogas and then digestate which is often composted with GO. This type of integrated system has shown a reduction in processing time by up to 40%, a removal of the need to treat the effluent water and savings on capital and operational cost due to smaller and more efficient systems (Kraemer and Gamble, 2014). This approach, enabling the capture and beneficial use of both biogas and nutrients from FO, is more in line with circular economy principles.

1.2 Opportunities for UOW management through active linkage between the waste, wastewater and energy sectors

As indicated, Australia has legislated emissions reduction targets (AUS PM, 2022) and signed the Global Methane Pledge (GMP, 2021). All Australian States and Territories have now committed to net zero emission targets by 2050 with interim targets around 2030 (Appendix Table 5). In this context, both the waste and wastewater sectors have an opportunity to play a key role in achieving the net zero targets through their management of organics. In addition, many have set their own reduction targets (Appendix Table 5).

Organic waste decomposition under anaerobic conditions in landfills is now known to contribute to methane emissions (Bogner, et al., 2007). Methane, when released to the atmosphere, has a Global Warming Potential (GWP) of 27-30 over 100 years (IPCC, 2021). Although it lasts only a decade, much less time than CO_2, but it absorbs much more energy than CO_2 and consequently has a higher GWP than CO_2. Therefore, measures such as flaring of landfill gas have been applied to mitigate the impact of methane on global warming. Although this measure does decrease the impact on global warming, it is a lost opportunity in terms of capturing methane for energy generation. Hence, capturing biogas for energy can not only mitigate climate change impacts but also be a source of renewable energy. AD produces both biogas (a mix of methane (50-75%), carbon dioxide, hydrogen sulphide, water vapour and traces of other gases) and digestate (solid and liquid material end-products of the AD process). While biogas can be used for the generation of energy, the digestate is rich in carbon and nutrients (nitrogen, potassium and phosphorous) that can be extracted and applied to land. These two key outputs can provide multiple cross-sectoral benefits.

Focusing on the opportunity to combine multiple sources of organic waste that arise in the urban environment and that can be processed together at WWTPs to generate biogas for energy brings together the typically siloed waste, wastewater and energy sectors and enables cross sectoral policy objectives to be aligned. By bringing these sectors together, WWTPs have the potential to transition from the usual business-as-usual model of merely treating wastewater, to a new role of a bio-refinery. In this process, multiple streams of organic waste can be accepted, and in addition to the outputs of treated wastewater, they can produce energy that can be utilised for the generation of electricity, heat, or fuel. In addition, the process can provide the ingredients to generate a range of bio-products, including bioplastics, and in so doing become the heart of a circular economy hub. Examples of such hubs are already implemented in various international cities (Jazbec, et al., 2020 and Jazbec and Turner, 2018).

Processing organic waste at WWTPs could provide the waste sector with an opportunity to process the organic waste more locally. This is particularly relevant in large urban settings, such as Sydney, where different waste streams are often transported long distances to be processed either at the periphery of the city or even further into regional areas, sometimes hundreds of kilometres away from the original source. Being able to process waste locally could offer cost savings particularly in relation to transport. Alternative organic processing facilities, such as industrial composting, require large land areas which is expensive to obtain in urban settings. In addition, gaining social licence for a new organic processing facility in an urban area could pose other issues, especially concerns due to odours. As WWTPs are already well established within urban environments, many with AD technology already being used, they provide an opportunity to avoid many of these potential issues.

Other benefits of processing UOW via AD include generation of renewable energy. Biogas generated via AD can be stored and dispatched at the time of need, providing an important element in energy demand management. Having a renewable resource available at a time when other renewable energy generation is idle, e.g., solar, could offer an alternative to battery storage solutions. Further, being able to generate biogas and store it at any time could provide WWTPs with an economic advantage from the cost of electricity generated from biogas. An alternative application of biogas could be fossil (natural) gas replacement. Considering fossil (natural) gas infrastructure is already established, this enables an easy application for biogas through direct injection into the gas pipeline network. It also provides a solution for the gas industry in terms of their GHG emissions mitigation options, as well as savings for consumers who can keep using existing gas infrastructure but powered with a renewable source. In addition, biogas can be applied and used for any industrial process that uses fossil (natural) gas and it can also be used as a transport fuel, an application readily adopted internationally (Jazbec and Turner, 2020).

Digestate, the other key output of AD, also has many beneficial applications. It can be used as organic fertiliser, for horticulture products (e.g., soil amendment, peat moss replacement, plant pots), for crop irrigation, animal bedding, and other products (e.g., building materials, bioplastics, etc.).

AD distributed within the urban environment (e.g., as part of the process within various established WWTPs) could therefore provide direct access to two key resource outputs locally, that is, biogas (energy) and digestate (especially nutrients). Both these resources are required within urban areas and would need to be imported from external sources, where they are generally generated.

Utilising existing WWTPs for AD therefore have multiple benefits such as the potential to:

- achieve cross-sectoral policy objectives;
- avoid organic resources ending up in landfill along with the substantial detrimental economic, social and environmental impacts;
- provide an opportunity to harness significant resources (renewable energy and nutrient rich digestate) at a more local scale;
- avoid long planning approval processes for new infrastructure which are often a roadblock in the waste industry;
- minimise infrastructure capital and operating costs due to augmentation of existing premises;
- utilise existing AD expertise and management knowledge already within the wastewater industry; and
- provide agile short, medium and/or long-term AD capacity opportunities as cities, such as Sydney, grow.

2 Research approach

The objectives of this study are to estimate the quantities of various UOW streams within defined illustrative case study areas and to identify the higher order circular economy benefits of redirecting unavoidable UOW to AD to help reduce the impacts of organic decay in landfills, lower GHG emissions, generate renewable bioenergy and recover nutrients. This study's particular focus is to explore the potential of using existing AD infrastructure (specifically Sydney Water's WWTPs with current and anticipated future latent capacity) for co-digestion of UOW streams. In so doing, this highlights the benefits of using existing cross sectoral assets to defer capital infrastructure costs or potentially avoid construction of new AD infrastructure assuming that the generation of UOW will actually decline per capita overtime. This is expressed as an objective for the food component of UOW within the current National Food Waste Strategy (AUS, 2017) and is further refined through subsequent reporting (FIAL, 2021) that is, preventing food waste generation as much as possible in the first place and where wastage occurs, moving the material produced up the food waste hierarchy to beneficial reuse and animal feed (FIAL, 2021).

This study brings together the typically siloed waste, wastewater, and energy sectors to help harness these opportunities. It aims to fill knowledge gaps such as quantifying the various available UOW streams and their energy potential and geospatial proximity to Sydney Water AD assets. An analytical and mapping framework is developed that can be applied more broadly across Sydney and potentially to NSW and other jurisdictions to showcase the value of AD which, although used extensively in places such as Europe, has not yet been harnessed in Australia.

The methodology, described in detail below and in Appendix Section A.4, includes:

- identification of data sources that could be used to determine organic waste generation quantities;
- analysis of different approaches to estimate unknown quantities of organic wastes generated, particularly in the data poor commercial and industrial (C&I) sector;
- estimation and mapping of UOW streams for the selected LGA's including projections;
- generation of hot-spot maps for potential UOW;
- identification of potential illustrative options for co-digestion (including barriers, opportunities and relevant stakeholders);
- estimation of energy potential for selected options and identification of additional benefits such as co-digestion and diversion from landfill, nutrients recovery, GHG emissions savings; and
- sharing of learnings and provision of recommendations for future research, including scale up to a wider area.

2.1 Study boundaries

A simplified organics value chain is illustrated in Figure 2 and is discussed below. Organic waste streams arise from the agricultural production, harvest and storage, processing and packaging, wholesale and retail distribution and consumption stages. Figure 2 also illustrates collection and processing methods. The focus of this study is on possible co-digestion options at WWTPs. Therefore, the scope of this study is limited to relevant steps and streams along the value chain. Those areas in scope are highlighted in bold in Figure 2.

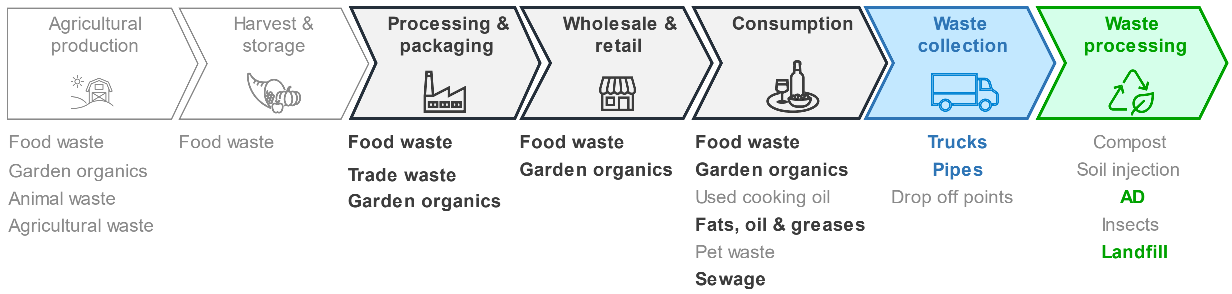


Figure 2: Organics value chain, including waste streams generated, collection methods and processing technologies. Study boundary is defined in bold.

Agricultural production, harvest and storage

Organic streams generated within agricultural production, harvest and storage include FO, GO, animal waste and agricultural waste. While organic streams generated at the production stage, on the farm, can also be processed through an AD and co-digested at WWTPs, they are considered to be out of scope for this study as the focus is on urban organics within Sydney.

Processing and packaging, wholesale and retail

FO, GO and trade waste streams generated during the processing and packaging, and wholesale and retail steps are captured in the C&I sector data and are considered in scope for this study.

Consumption

Several organic waste streams result from the consumption stage in both the residential and non-residential sectors. FO, GO, FOG, and sewage are suitable for co-digestion and are therefore considered in this study. UCO waste is not in scope, as within the non-residential sector it is typically already collected and reprocessed for stockfeed, pet food products or to make higher value fuels such as biodiesel (Scanline, 2020). This stream would however benefit from future research as unquantified volumes of this valuable resource are still lost to landfill and discharged to sewers (contributing to fatbergs), especially from the residential sector. Pet waste is estimated but is not included in the mapping or options analysis. Pet waste must currently be collected through the residual waste stream and disposed to landfill, and not through the FOGO stream (EPA NSW, 2022). However, there are various home composting systems on the market that facilitate landfill avoidance and nutrient capture within the subsoil to help avoid potential pathogen exposure. An estimation of the volumes generated is included to provide an illustration of other smaller UOW streams not typically included in organic waste management assessments.

Waste collection

Sewage is normally collected through the sewerage network. Other forms of UOW are normally collected via trucks. FO could also be collected through piped systems, both with and without sewage, such collection methods are applied internationally. However piped networks are not considered for UOW collection (except for sewage) in this study. There is also an option to use drop off points for UOW. Again, such systems, applied internationally, are not in scope. Both systems have the potential to be adopted in Australia in dense urban areas and are an interesting area for future research exploration.

Waste processing

The waste processing technology used in this study is AD, with landfill used for comparison.

2.2 Data collection and analysis

As this study focuses across three different sectors: waste, wastewater and energy, the relevant data is also segregated across the three sectors, each with different data custodians and reasons for collecting the data that is useful to this study analysis. While some of the data is readily available, other data has been challenging to obtain. Some of the data used in the analysis was needed to be compiled from various datasets. The accuracy of the data due to collection methods and purpose poses challenges especially in relation to the potential breaching of privacy laws. Appendix Table 7 summarises the data types, sources sought to obtain the data together with challenges, reliability and access issues.

Data collection framework

Figure 3 illustrates data needed for the project outputs. Sources of data and challenges obtaining it are summarised in Appendix Table 7. The methodology used to derive project outputs is shown in Appendix Figure 38 and is described in Appendix Section A.4.

Project outputs

Data inputs	LGAs profile	WWTP profile	Businesses profile	FO	GO	FOG	Trade waste	sewage	Renewable energy	Electricity generation	Bioenergy potential	GHG emissions	Biosolids	UOW projections	Demographic projections	Bioenergy potential projections
Geospatial data				●	●	●	●	●			●					
Household type data	●			●	●			●						●	●	●
Business type data			●	●	●											
Employment data			●	●	●											
Residential waste data	●			●	●					●	●	●	●	●		●
Non-residential waste data	●			●	●					●	●	●	●			
Pet waste data	●															
FOG data						●				●	●		●			
Trade waste data							●									
Sewage: res. and non-res.		●						●	●	●	●		●	●		●
WWTP operational parameters		●								●	●		●			
Bioenergy potential											●					●
Renewable energy	●								●							
Future projections														●	●	●

Figure 3: Data collection framework.

2.3 Geospatial mapping

Estimated feedstock availability and bioenergy generation potential is mapped at the *Statistical Area 1* (SA1) level. This is a spatial unit of analysis, part of the *Australian Statistical Geography Standard* (ABS, 2021b), and each SA1 is sized to contain approximately 400 people. The geospatial mapping is performed for the four identified case study LGAs, divided into two groups. Group 1 is associated with two adjacent WWTPs and Group 2 with one WWTP, as discussed in Chapter 5 and Chapter 6. The LGAs, LGA groups and the SA1 spatial resolution are shown in Figure 4.

UOW streams are calculated and mapped at the SA1 level. The detailed method used for the geospatial mapping is described in the Appendix Section A.4 together with the waste generation rates and factors applied in the calculations (Appendix Table 10 and Appendix Table 11).

Figure 4: Illustration of the statistical area 1 (SA1) scale for LGAs in the study area.

2.4 Energy potential

Energy potential from digesting feedstock is estimated based on assumptions and parameters from the academic literature (see Appendix Section A.4.10). Methane and electricity generation is estimated for each feedstock, assuming mono-digestion. The purpose of this analysis is to characterise the maximum methane and electricity generation *potential* from each feedstock in the study area. Of course, the actual available will be less than this due to various factors including for example the level to which avoidance targets are achieved, actual growth, useable materials and/or ways in which contamination issues are dealt with.

2.5 Stakeholder engagement

An Industry Reference Group (IRG) was set up at the commencement of the project for stakeholder engagement to ensure the views and priorities of the industry, end use consumers and other key stakeholders are considered during the project as much as feasible. Three points of stakeholder engagement were planned during the project: at the inception, mid-point and conclusion.

At the **project inception**, a workshop was held to set up project expectations and ensure that the project addresses industry issues as much as feasible. The synthesised outcome of the workshop is included in the Appendix Section A.7.

At a **project mid-point** the stakeholder engagement included a workshop with presentation of preliminary results. The aim of the workshop was to identify the options for co-digestion, explore opportunities and barriers and identify relevant stakeholders for the potential options. Workshop findings are synthesised in Appendix Section A.8.

A **final stakeholder engagement** is planned at the launch of the final report of this project. It will take the form of a roundtable discussion, with the aim of identifying the priorities and next steps for research for the participants. The identified priorities and next steps, in addition to the study findings, will form the foundation of a proposed RACE project proposal for the next stage.

3 Who are the stakeholders?

Stakeholders along the organics value chain are distributed across three sectors: residential, commercial and industrial, and institutional. They are further segregated across the waste, wastewater, and energy sectors. Figure 5 illustrates the stakeholders that were identified as part of this project along the organics value chain. However, only some of the stakeholders were engaged in this relatively short project, either as IRG members or as project funding partners.

Agricultural production	Harvest & storage	Processing & packaging	Wholesale & retail	Consumption	Waste collection	Waste processing
Federal Gov' • Regulator • Net zero targets • Catchment management **State Gov'** • DPI • NSW EPA	**Federal Gov'** • Regulator • Supply chains **State Gov'** • Health regulations • Food safety • Logistics (cold chains)	**Federal Gov'** • Regulator • Net zero/waste targets • Standards **State Gov'** • Sustainability Advantage	**Federal Gov'** • Regulator • Product Stewardship **State Gov'** • OEH • Health regulations	**Federal Gov'** • Regulator • Behaviour programs • Prisons • Aged care • Research (CRCs, FIAL) **State Gov'** • Health regulations • Hospitals • Schools	**Federal Gov'** • Regulator • Net zero/waste targets • Research (University) **State Gov'** • NSW EPA • Planning (E.g. GSC)	**Federal Gov'** • Regulator • Net zero/waste targets • ARENA • Research (University) **State Gov'** • NSW EPA • Utilities, Sydney Water • IPART
Local Gov' • Local land services • Regional councils	**Local Gov'**	**Local Gov'**	**Local Gov'**	**Local Gov'** **Institutions** • Schools • Hospitals • Prisons • Aged care	**Local Gov'** • Waste management • Waste collectors • Planning • Procurement • Policy	**Local Gov'** • Organics processing • Planning • Procurement • Policy
Private org' • Agriculture Ind • Crop farmers • Livestock farmers • Agricultural advisors • Fertilisers **Industry bodies** • NSW farmers ass'	**Private org'** • Workforce **Industry bodies** • Food Authority	**Private org'** • Food manufacturing • Food packaging • Breweries • Workforce **Industry bodies** • APCO	**Private org'** • Workforce • Wholesale • Retail (Woolworths, Coles, Aldi, Harris Farm) • Compost retailers • Property developers • Markets	**Private org'** • Restaurants, cafes, fast food, hotels • Workforce • Food banks (OzHarvest) **Industry bodies** • Food banks • Circular Australia	**Private org'** • Management (waste/building) • Waste collectors • Utilities • Property developers • Consultants **Industry bodies** • NSW WCRA, WARR	**Private org'** • Landfill operators • Organics processors, e.g. compost, AD, horticulture • Utilities • Property developers • Energy suppliers/users • Biosolids **Industry bodies** • WMRR, AORA
Community • Households			**Community** • Households • Markets	**Community** • Households • Community org'	**Community** • Households • Community org', e.g. Hobo Gro, Share waste	**Community** • Households • Community org', e.g. Hobo Gro, Share waste

Figure 5: Stakeholders along the organics value chain.

3.1 Stakeholders in the waste sector

The waste management system includes collection and processing of waste from the residential and non-residential C&I (including institutional) sectors. The waste management system in Australia is complex and is distributed among multiple stakeholders who are a mix of government and private organisations. The approach to waste management is not uniform and varies between LGAs. The collection options are typically driven by the processing options available and contractual agreements. Residential organic rich waste, such as FO, GO, pet waste and UCO, are normally managed by local councils, who either run their own collection system or subcontract the collection to private waste collection companies. Options available for waste collection for residents vary from provision of separate bins for FO, GO, and residual waste, to offering only a general waste bin. Some councils offer GO bins, others offer a combined FOGO bin, and a small number offer a FO only bin (see Appendix Table 6). Specialised waste trucks collect segregated waste streams in the bins, emptying the bins into trucks onsite. These trucks take waste either to a transfer station or a processing facility.

Contractual agreements for collection and processing of waste are usually long term (around 10 years) and therefore make it hard to introduce changes to the service without some form of contractual penalty. Some councils have grouped together through Regional Council Organisations (RCOs) to establish more favourable and uniform contractual agreements. The difference in collection services across LGAs makes it difficult to communicate with residents about waste collection. This often leads to confusion about separating waste streams within the home and issues related to poor waste source separation and contamination.

In the non-residential sector, individual property owners, tenants or managers usually sign individual contractual agreements to have their waste collected, mostly by private waste management entities. These contracts are usually for shorter-term periods compared to residential contracts. A small proportion of businesses have their waste managed through local council arrangements. Again, this varies across LGAs.

There are now also a growing number of on-site collection and treatment processes such as home composters and worm farms in the residential sector but also dehydrators, macerators and even units bio-converting FO using black soldier flies in the non-residential sector (Turner, et al., 2017 and Turner, et al., 2019), further complicating the assessment of the UOW generated, the current system and the associated stakeholders.

Processing, recycling facilities and landfills are generally all run by different stakeholders to the waste collectors. However, some of the bigger waste management companies manage all steps of the waste management process, while others tend to specialise on a particular stream and/or step within it.

3.2 Stakeholders in wastewater

While most solid organic waste is collected via trucks, liquid organic waste (mainly sewage and some types of trade waste) are collected via a piping network leading to a WWTP. The whole wastewater collection and processing system is usually managed by one entity. Sydney Water, a state-owned corporation, manages the vast majority of the wastewater in the Greater Sydney area, while individual councils typically manage services in each LGA in regional NSW.

Another liquid organic waste in Sydney, FOG, is collected by any of nearly 30 licensed Wastesafe transporters registered with Sydney Water (Sydney Water, 2022a) and processed through various methods, including for example the only commercial AD plant in Sydney and soil injection.

There are several possible options for processing liquid organic wastes. Sewage processing includes separation of the solids from water, which is further purified to be released back into the environment. The resulting sludge can then be further processed for generation of biogas and biosolids. Biogas is used to generate energy (natural gas replacement, electricity, heat, fuel). Biosolids, which contain nutrients (e.g. nitrogen, phosphorus, potassium) can be applied to land. While the WWTPs manage generation of biogas and biosolids, the use of biogas is either on site or is supplied to a different stakeholder. Biosolids are further managed by external stakeholders to the WWTPs. In Sydney, approximately 75% of biosolids produced are used on around 40 farms across the central west and southwest of NSW to improve soils. The remaining 25% are further processed, often through composting, by other stakeholders for a range of agricultural, horticultural, rehabilitation, garden, forestry and parkland uses (Sydney Water, 2022b).

3.3 Stakeholders in energy

If generated energy (biogas) from AD is used outside the WWTP, stakeholders external to the WWTP are involved depending on the application. The applications vary from feeding electricity to the grid, injecting biogas to the gas pipeline network, suppling biogas fuel for transport or utilising heat for businesses external to the WWTP. All these applications involve different stakeholders.

3.4 Bringing together stakeholders from waste, wastewater, and energy

One of the main challenges for a successful development of a co-digestion system for UOW is to break the established waste, wastewater, and energy sector silos, for example, by enabling productive dialogue and developing an understanding of the various components and complexity of the UOW system, including each of the relevant stakeholders' strategies, objectives, opportunities and concerns. It also requires government policy support, modifications in the existing regulations to enable cross sectoral arrangements, and establishment of new governance approaches across the sectors as well as opening up of market opportunities. Further, the relevant stakeholders require internal changes enabling the collaboration, modification of their costs and benefits assessments to accommodate externalities and establishment of new contractual agreements with different stakeholders. That is, a complex web of challenges that need to be overcome.

Priorities identified in this study

In this study, project partners and the IRG group identified the following priorities in bringing together stakeholders from the waste, wastewater, and energy sectors:

- **Map of the stakeholder urban organics value chain**:
  - map stakeholders along the value chain; and
  - identify stakeholders' roles in unblocking the feedstock for co-digestion.
- **How to brake cross sectoral barriers:**
  - understand the alignment between councils, Sydney Water, DPE and energy users in planning;
  - ensure that the different values in sectors are considered.
- **Understanding of UOW processing options:**
  - understand current waste streams and processing options for the available markets in Sydney;
  - understand the geographical distribution of the UOW, viable waste treatment distance and feedstock fluctuations;
  - identify UOW options value;
  - identify energy potential and storage needs;
  - identify operational risks and benefits;
  - determine gate fees and cost-effective collection and processing opportunities;
  - understand gains of co-digestion;
  - identify diversion of organic waste from landfills;
  - determine the impact on council's current FO reduction strategies and barriers.
- **Processing UOW through AD:**
  - build an understanding and trust in AD processing;
  - identify pathways for impactful outcomes;
  - identify barriers related to existing contracts and assets, policy, approval pathways, commercial and technological limitations;
  - identify optimal use of feedstock based on costs and benefits, dedicated infrastructure for co-digestion (existing or new), sites (demand and organic waste types);
  - identify what supporting infrastructure is required (transfer stations, treatment, de-contamination, maceration, etc.);
  - provide information for the stakeholders involved in planning and investment.

- Commercial and industrial UOW:
    - identify commercial offerings for businesses to take their waste to WWTPs.
- Research framework for knowledge sharing:
    - develop a framework for broader waste mapping, data sharing and conversion factors of different FO to gas/energy (e.g., kg to kWh).

Some of the listed priorities are in the scope of this study and are addressed in this report, others are recommended as next steps for research as summarised in Chapter 9.

4 Wastewater treatment plant case studies

WWTPs are designed to treat wastewater, one of the UOW streams, with treated effluent released back to the environment according to required environmental standards. Sludge collected from the WWTP process can be further treated through AD to capture biomethane for energy generation. AD at WWTPs can be modified to accept other organic feedstock, such as FO, FOG, and other organic trade wastes. WWTPs are typically built with capacity to accommodate population growth. This project considers three potential WWTPs, out of Sydney Water's 14 existing WWTPs, suitable to accept external UOW feedstocks for co-digestion.

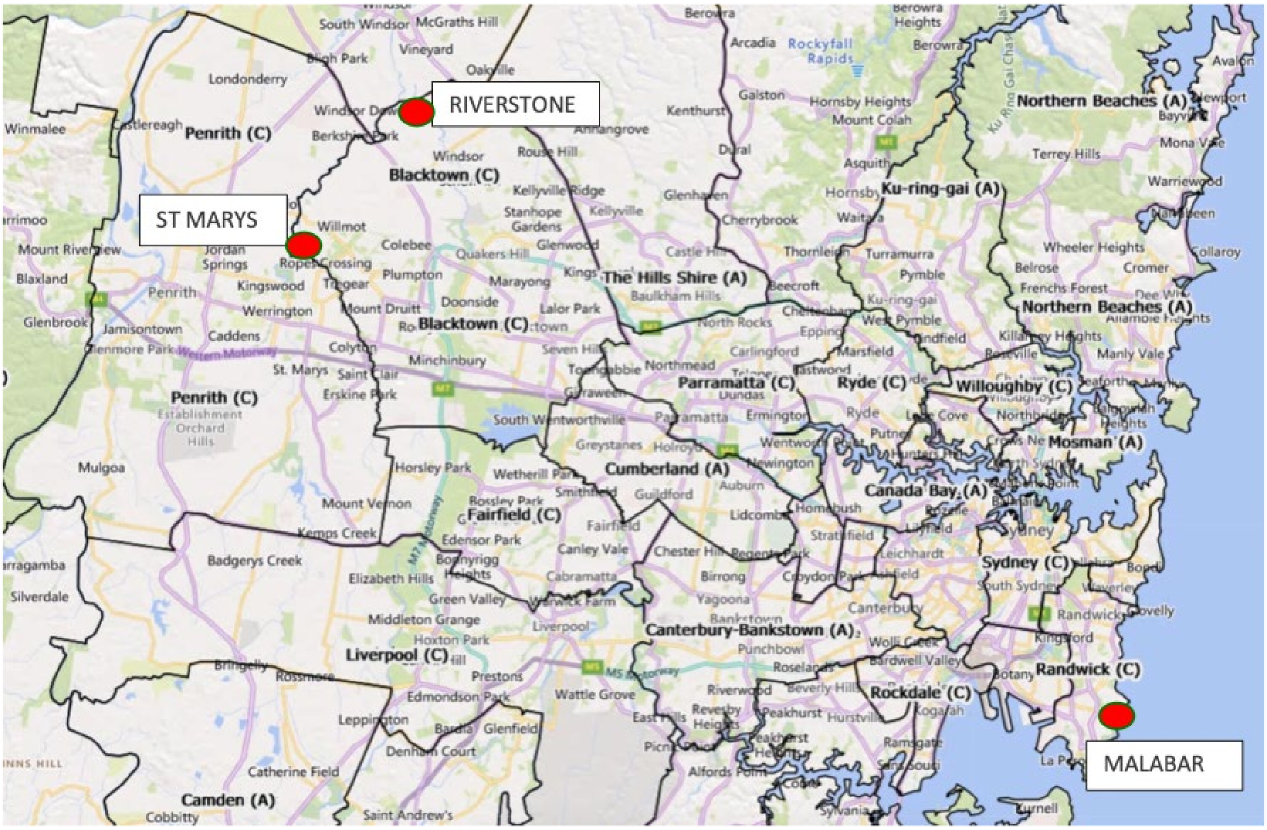


Figure 6: Location of selected WWTP for the case studies.

The three case study sites are selected based on Sydney Water's priorities which they developed based on the digester sludge volatile solids loading rate capacity, latent loading capacity (considered in conjunction with catchment growth projections), and substrate dose rates. In addition, site assessments such as digester stability and capability of existing ancillary systems (heating, mixing, sludge pumping, solids handling and biogas management systems) informed the selection of the WWTP case study sites.

The three WWTPs used for the case study analysis are Malabar, St Mary's and Riverstone (Figure 6), which service Bayside, Randwick, Blacktown and Penrith LGAs. Table 2 below provides summary information including digestor capacities and planned timelines.

Table 2: WWTPs selected for the case studies.

Malabar WWTP	St Mary's WWTP	Riverstone WWTP
		
• Three 10,000 m^3 ADs and one 4,500 m^3 AD (2 primary, 1 secondary, 1 tertiary) • Capacity to take 125 kL/day FO (up to 12 trucks) • Available for co-digestion: mid 2023	• Four 2,700 m^3 AD (3 primary, 1 secondary), one thermal hydrolysis (CAMBI) – 45 t DS/day at peak load • Capacity to accept 75 kL/day FO (up to 7 trucks) • Conversion from aerobic to anaerobic mid 2023	• Two 1,380 m^3 ADs and three 6,000 m^3 ADs (3 primary, 2 secondary) • Capacity to accept 140 kL/day FO (up to 10 trucks) • Commissioned by mid 2024

5 Urban organic waste in the case study LGAs

This section summarises the baseline results for the UOW for LGA Group 1 (Penrith and Blacktown) adjacent to St Mary's and Riverstone WWTPs, and LGA Group 2 (Randwick and Bayside) adjacent to Malabar WWTP.

5.1 LGAs' background

Almost a million people, 18% of the Greater Sydney population, live in the four LGAs considered in this study. In LGA Group 1 – (western LGAs), the population mostly live in single unit dwellings (SUDs) or houses. Conversely, in the eastern LGAs (Randwick and Bayside) the majority of the population live in multi-unit dwellings (MUDs) such as apartment blocks. This is also reflected in the population density, which is significantly higher in the eastern LGAs, although in all four LGAs the population density is higher than Greater Sydney's average (425 people/km^2). Demographics, businesses, organic streams and renewable energy generation in Blacktown, Penrith, Randwick and Bayside are summarised in Table 3. As noted in Appendix Table 7, the UOW statistics are based on estimates drawn from multiple disparate data sources.

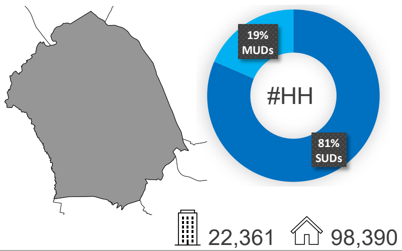
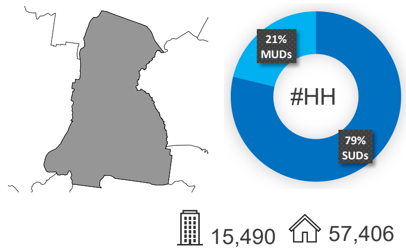
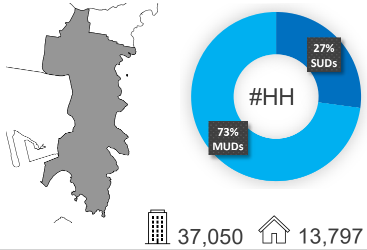
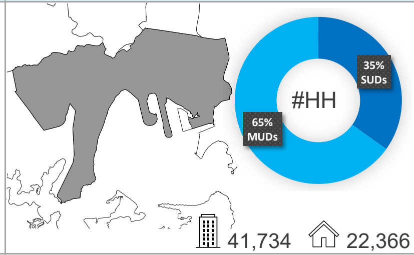
Waste audits performed across the Greater Sydney region and NSW observe a variation in the generation of FO and GO based on the dwelling type. Therefore, distribution of dwelling types is an important factor to take into account when considering the economics of separate collection of either FO or GO as opposed to a combined FOGO collection (Rawtec, 2020) and are considered in this study.

About 3% of the Australian businesses (32,156) are within these four councils, with Blacktown generating 3.5% of Gross State Product (GSP). Across all four councils (Figure 7), about 20% are *Construction* businesses[4] (as per ANZSIC codes grouping itemised in Appendix Table 8), followed by *Professional, Scientific and Technological Services* groupings. While Randwick has a significant number of businesses in the *Health Care and Social Assistance* group, in the other LGAs *Transport, post and warehousing* is one of the main groups. The *Accommodation and Food Service* group, anticipated to generate large amounts of FO, is also one of the main groups in LGA Group 2 (Randwick and Bayside LGAs).

More than 95% of the businesses are small, employing 1-19 people, with only 31 businesses across all four LGAs employing more than 200 people. Business types and size could provide an insight into the likely type of organic waste that can be anticipated to be generated and in what quantities. Their size and distribution could potentially impact consideration of the most efficient collection methods of the organics' streams. Therefore, this study aims to develop FO and GO generation factors depending on the business types and size.

[4] A large proportion of these are likely sole trade businesses considering that more than 95% of the businesses in the study areas are small employing 1-19 people.

Table 3: Overview of the Council's demographics, business activity, organic waste streams and energy potentials.

Council	BLACKTOWN CITY COUNCIL		PENRITH CITY COUNCIL		RANDWICK CITY COUNCIL		BAYSIDE COUNCIL	
Households								
Supplying WWTP	Riverstone, St Mary's		Riverstone, St Mary's		Malabar		Malabar	
RESIDENTIAL								
Population	399,711		219,149		135,275		176,061	
Density	1,665 /km²		541.4/km²		3,723 /km²		3,526/km²	
NON-RESIDENTIAL								
Businesses	12,059		7,343		5,507		7,247	
Employees	128,292		76,801		48,475		76,544	
ORGANIC WASTE STREAMS								
Bin collection	 weekly		 fortnightly	weekly	 fortnightly	weekly	 weekly	fortnightly
	residential	non-residential	residential	non-residential	residential	non-residential	residential	non-residential
Food waste	31 kt/y	15 kt/y	15 kt/year	8 kt/year	6 kt/y	5 kt/y	16 kt/y	12 kt/y
Garden organics	31 kt/y	12 kt/y	34 kt/year	7 kt/year	9 kt/y	4 kt/y	3 kt/y	9 kt/y
FOG		1,116 kL/y		690 kL/y		553 kL/y		843 kL/y
Sewage	19 GL/y	4 GL/y	10 GL	3 GL/y	7 GL/y	2 GL/y	10 GL/y	3 GL/y
Trade waste		3 GL/y		1 GL/y		1 GL/y		3 GL/y
EXISTING RENEWABLE ENERGY								
Solar	11.3 MW		5.5 MW		0.8 MW		1.1 MW	
Hydro	3.7 MW							
Biomass	1.2 MW		2.8 MW		4.7 MW			

* General waste collected fortnightly in SUDs and twice per week in MUDs

* * FOGO only available in SUDs, no organics collection in MUDs

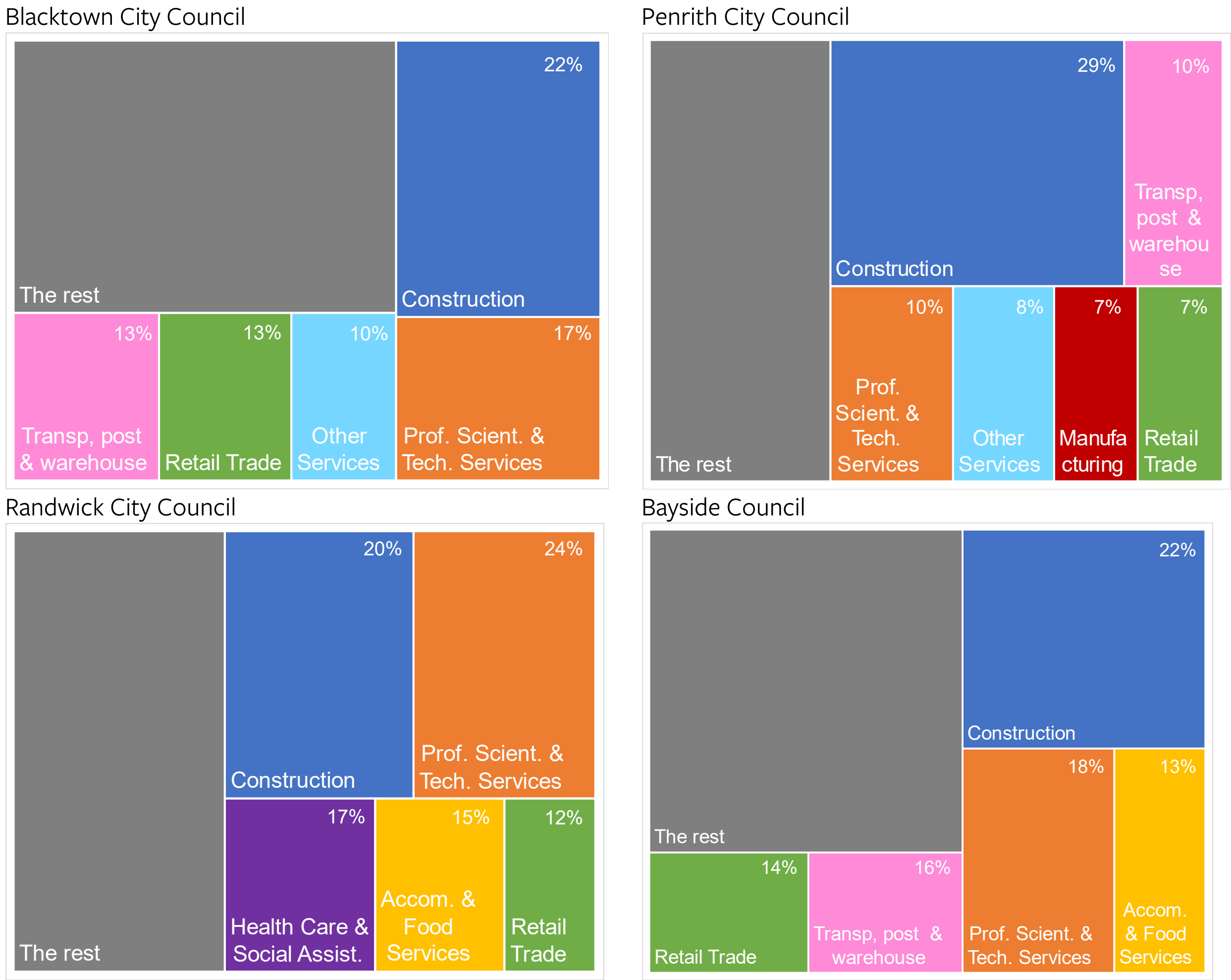


Figure 7: Distribution of Business types for Blacktown, Penrith, Randwick and Bayside council by number of businesses.

Across the four councils, an estimated 68 kt/y of FO was generated in the residential sector in 2020/21, and 40 kt/y of FO in the non-residential sector, a total of 108 kt/y. In addition, it was estimated that 77 kt/y of GO was generated in the residential and 32 kt/y in the non-residential sector, a total of 109 kt/y (e.g., a similar quantum to FO). WWTPs are already processing 58 GL/y of sewage from the four LGAs, of which the majority, approximately 79%, is from the residential sector. An estimated 8 GL/y of trade waste was produced in 2020/21 in the combined study area and 3.2 ML/y of FOG.

Generation of biomethane via AD from the organic waste streams could potentially add to the existing renewable energy already generated from the four LGAs. Almost 19 MW of solar panels have been installed in the LGAs, producing roughly 27,740 MWh energy per year. Current installed renewable energy generation from biomass in the LGAs is almost 8 MW, mostly from the existing AD systems operating within the WWTPs. Capturing energy from the other organic streams, such as FO and FOG, could add to the renewable energy generated in the area.

5.2 Urban organic waste generated in 2020/21

This section aims to quantify and geospatially map the estimated UOW streams generated across Blacktown, Penrith, Randwick and Bayside councils. In Figure 8 the total estimated FO and GO in t/y arising from the residential and non-residential sectors are plotted. Some of the FO and GO were source separated and recycled (44% in the residential sector), however the majority of organics were disposed of in residual waste bins which go to landfill. While some of these organics were captured at AWTs, around 30% were still disposed to landfill.

As it can be seen from Figure 8, LGA Group 1 (Penrith and Blacktown), where people mostly live in SUDs (Table 3), as opposed to the LGA Group 2 (Bayside and Randwick), where people mostly live in MUDs (Table 3), generated significantly higher quantities of GO. On the other hand, Blacktown and Bayside generated more FO in total compared to Penrith and Randwick. Penrith and Randwick offer a separate FO collection via FOGO. Randwick introduced the FOGO collection in March 2021 for both SUDs and MUDs, although it had trialled separate FO collection in apartments since 2013. Penrith introduced FOGO weekly collection in SUDs in 2009 and switched the general waste collection in SUDs from weekly to fortnightly. In Penrith MUDs, there is no organics collection available and general waste bins are collected twice per week. The combined FO and GO generation per household is however the largest in Randwick and this is due to the large generation of GO (Table 10). It should be noted however that services offered across the four LGAs are different and have been changing over the recent years all impacting the collected organics and distribution across the bins. In addition, home composting is not included in the estimated generation. Table 10 lists generation per household for the LGAs and streams collected.

When comparing the non-residential sector, although Bayside and Penrith have a comparable number of businesses and employees (Table 3), Bayside produced significantly larger quantities of both non-residential FO and GO. However, the largest non-residential FO and GO appear to arise from Blacktown, which also has the largest number of businesses and employees (Table 3) and is currently the largest council by population in NSW. Randwick has the smallest number of businesses and employees of the four study LGAs and consequently produces significantly smaller number of FO and GO.

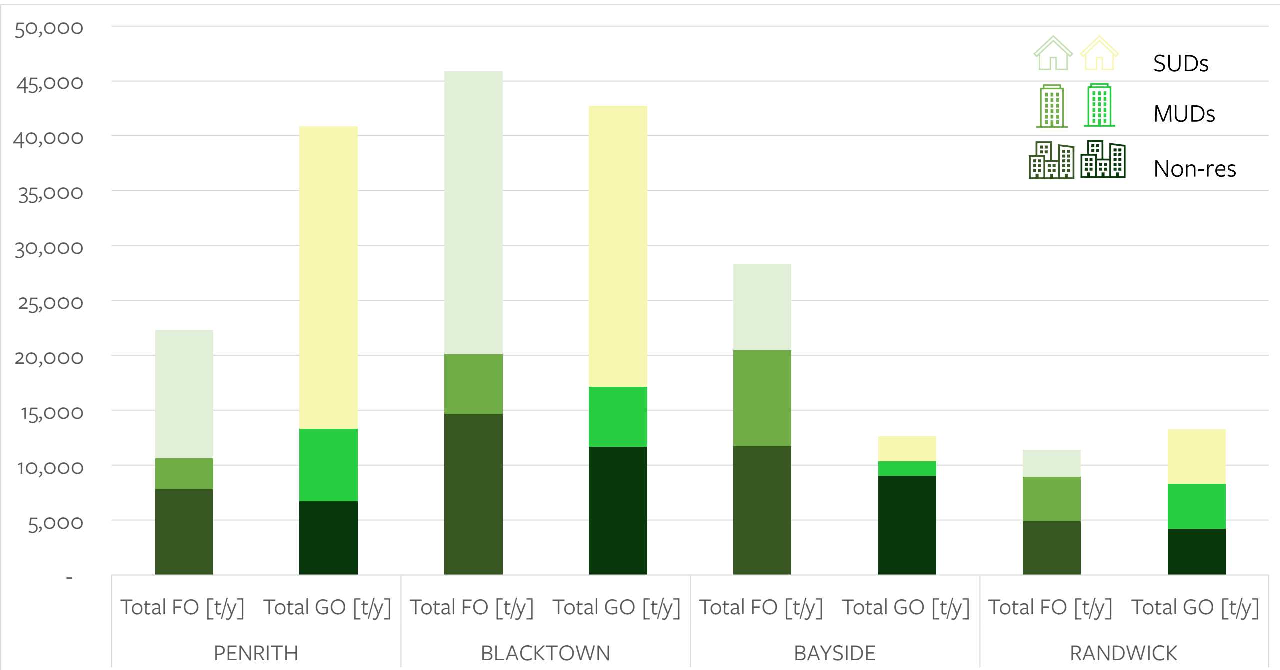


Figure 8: Total FO [t/y] and total GO [t/y] in residential (SUDs and MUDs) and in non-residential sectors by LGAs for 2020/21.

Figure 9 shows geospatial distribution of FO generation and Figure 10 shows geospatial distribution of GO generation mapped for both the residential and non-residential sectors for all four LGAs.

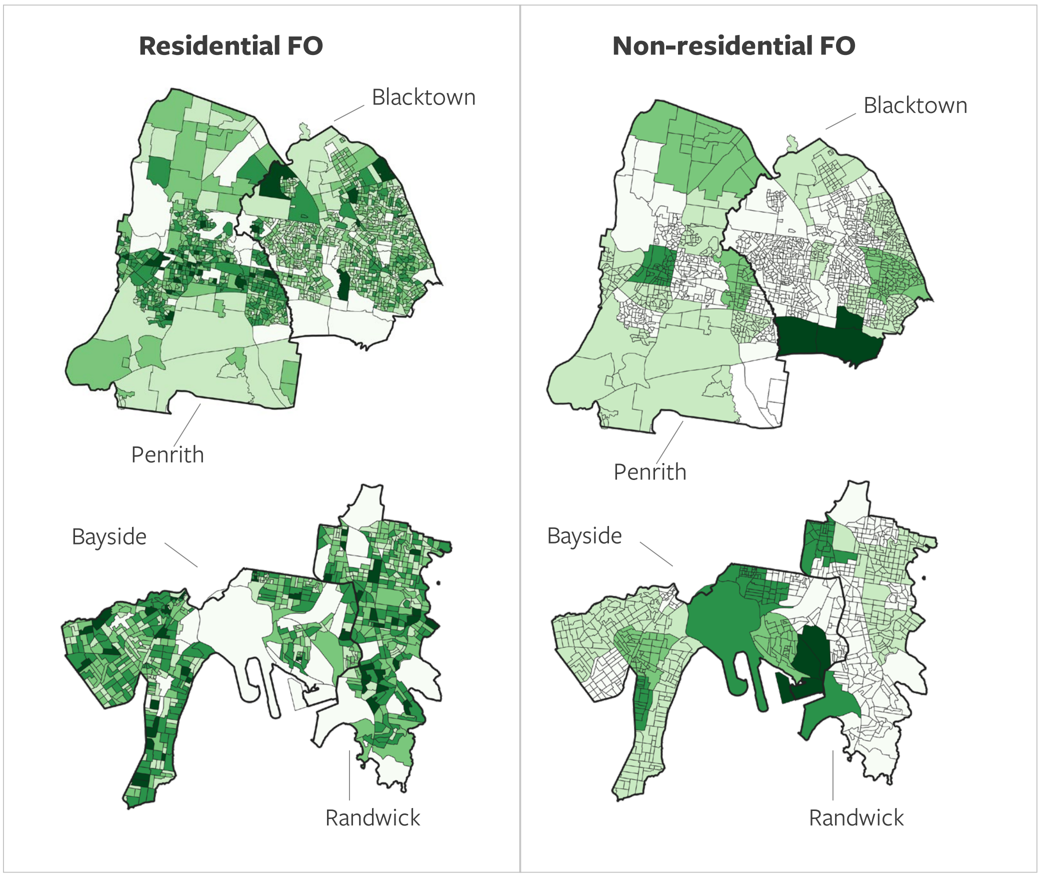


Figure 9: Geospatial distribution of estimated FO (SA1) in residential and in non-residential sectors by LGAs based on 2020/21 data.

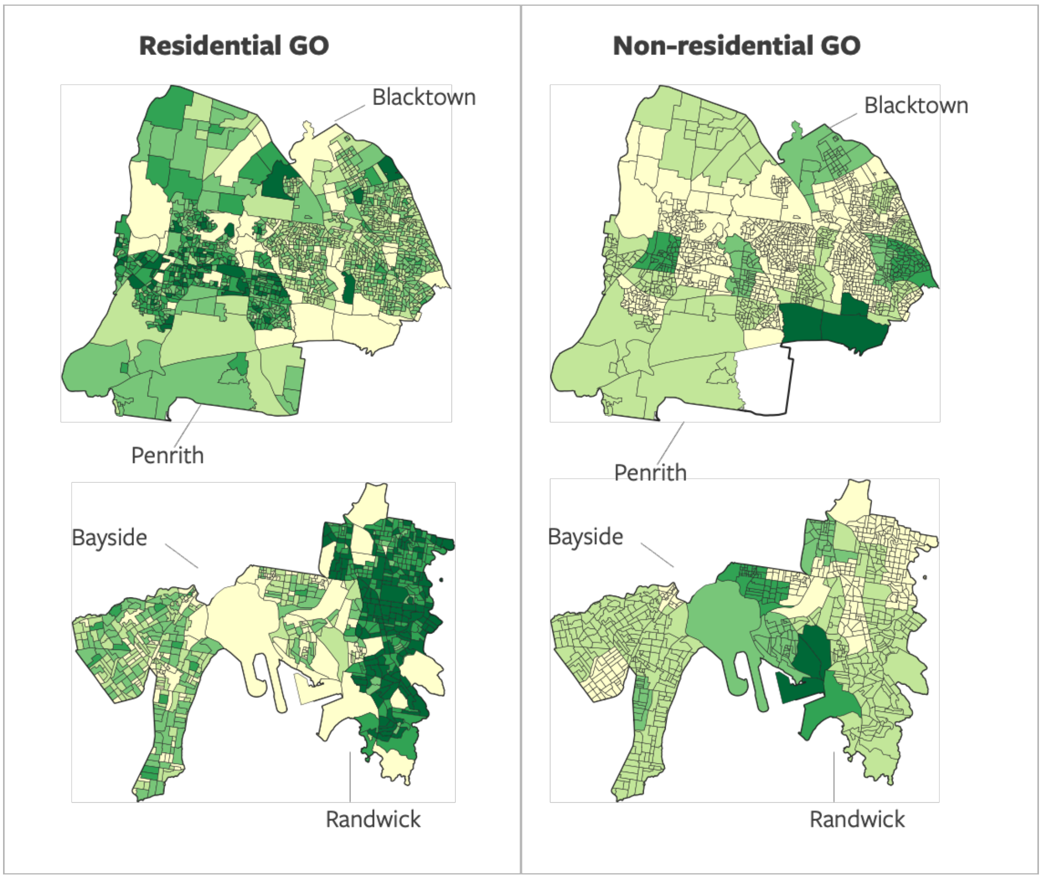


Figure 10: Geospatial distribution of estimated GO (SA1) in residential and in non-residential sectors by LGAs based on 2020/21 data.

Sewage generated in both residential and non-residential sectors is already treated by Sydney Water WWTPs and is either used or will be (as Sydney Water is adding ADs in their treatment processes) to generate bioenergy. In addition to Malabar WWTP, there are additional 6 WWTPs already generating energy from biogas. Additional 4 WWPT, including St Mary's and Riverstone, are being upgraded to include AD for energy generation at Sydney Water WWTPs. Within the case study LGAs, sewage predominantly arises from the residential sector (Figure 11). Figure 12 shows geospatially mapped sewage distribution for the residential and non-residential sectors for 2020/21.

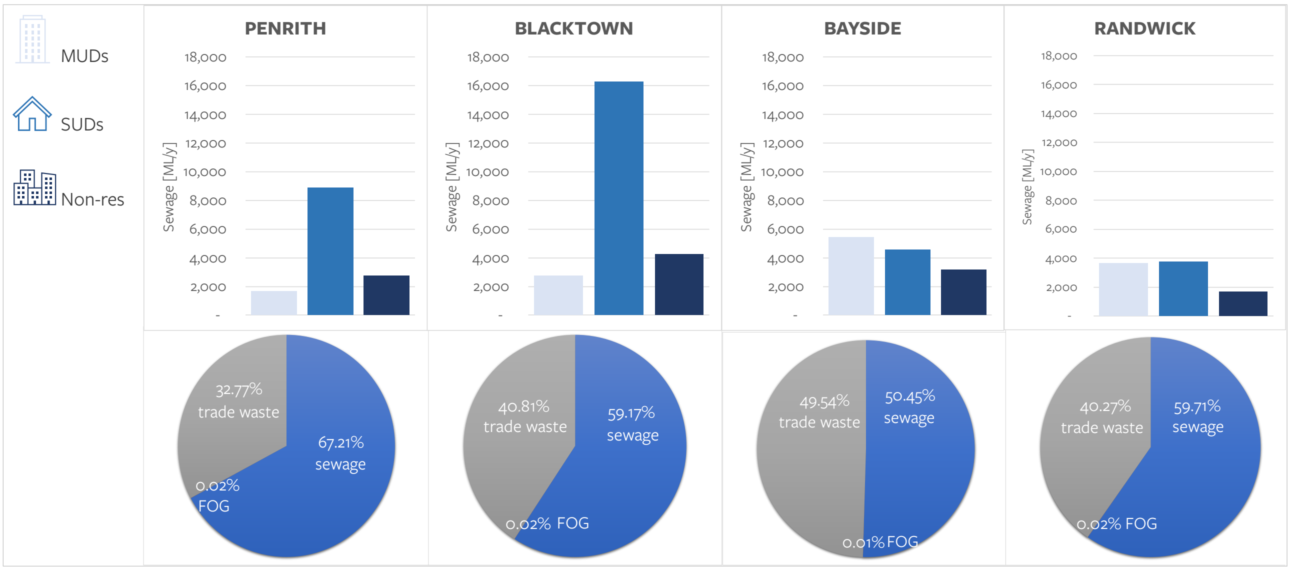


Figure 11: Sewage in residential (MUDs and SUDs) and non-residential sectors [ML/y]. Non-residential sewage as a percentage to trade waste and FOG in 2020/21.

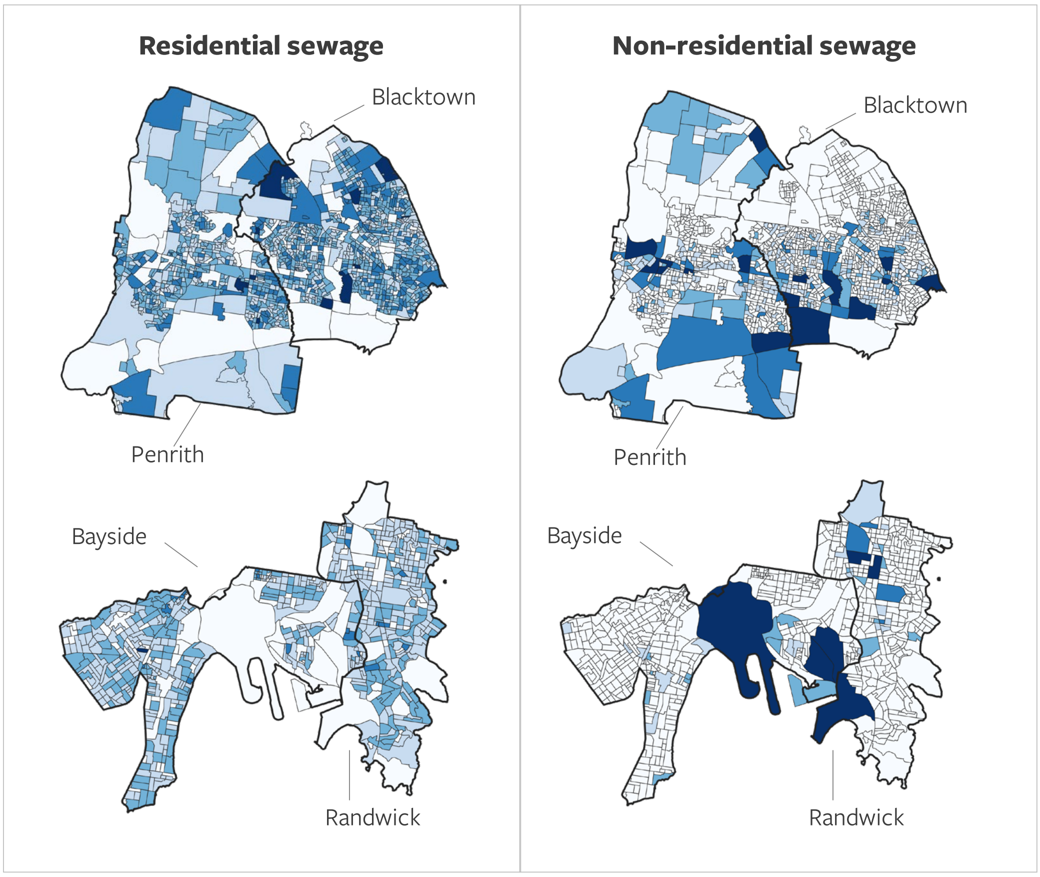


Figure 12: Geospatial distribution of estimated sewage (SA1) in residential and in non-residential sectors by LGAs for 2020/21.

In the non-residential sector, in addition to sewage, trade waste is also collected through WWTPs, as well as FOG through licensed collectors. In Figure 11, the quantities of sewage are compared to trade waste and FOG. Although quantities of FOG are relatively small, the energy potential of the AD system can increase significantly when FOG is co-digested with sewage.

Trade waste includes a broad range of commercial and industrial wastewaters produced at industrial or commercial premises that require different treatment equipment. Permits need to be issued for the trade waste to be discharged to the sewerage system and most of the waste needs some form of pre-treatment. Due to their variability in nature and therefore complexity, trade waste was only estimated in quantity and geospatially mapped (Figure 13) but was not considered for estimation of the bioenergy potential (Chapter 6). FOG is a type of trade waste collected via grease traps. This type of waste predominantly occurs in retail food businesses and if discharged directly to the sewer can cause blockages. Therefore, grease traps are required for such food related business and are emptied and collected by licensed Wastesafe transporters in Sydney, registered with Sydney Water (Sydney Water, 2022c), before further treatment for bioenergy and disposal via subsoil injection. FOG is geospatially mapped in Figure 13 for the study area. Its energy potential is estimated in Chapter 6.

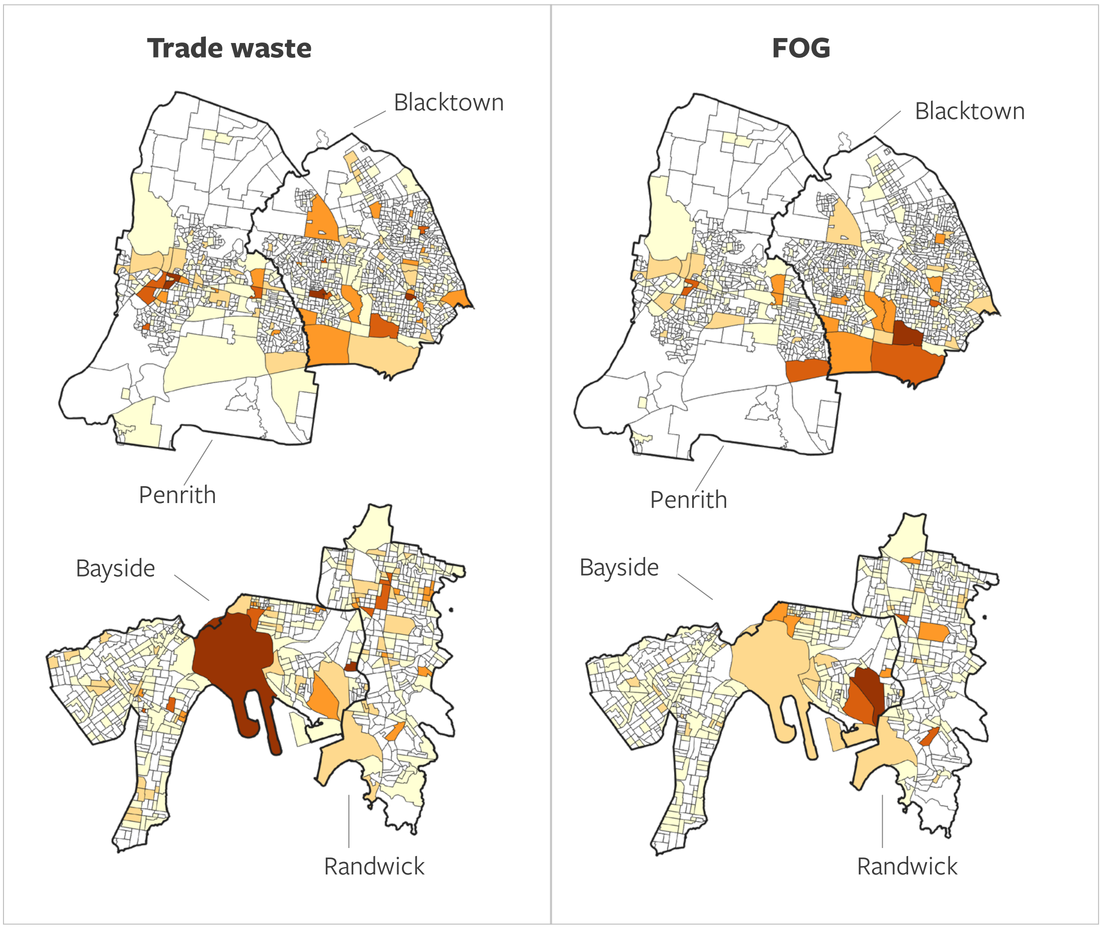


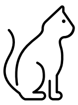
Figure 13: Geospatial distribution (SA1 level) of estimated trade waste and FOG by LGAs.

The graphs and geospatial mapping in this section identify the importance of observing contextual differences between LGAs in terms of the quantum and types of different UOW streams being generated and their potential for collection and treatment.

5.2.1 Pet waste

Pet waste is predominantly disposed to landfill in residual waste and is not considered in the UOW bioenergy potential calculations (Chapter 6). However, for illustrative purposes estimates are included here to show how unassuming waste streams can potentially represent surprisingly large volumes of waste. Approximately 4.8 million dogs and 3.9 million cats live in Australia and more than 60% of Australians own at least one pet (Hannink, 2020). Although an average dog produces only 340g of faeces per day (DoodyCalls, 2022), due to a large number of dogs such organics represent significant quantities. Similarly, although much smaller, is the impact of cat faeces – an average cat produces 50g of faeces per day (Michael, 2022). For the case study LGAs, it is estimated that pet waste could represent 20,466 t/y, which could be as much as one tenth of total waste currently disposed to landfill (e.g., residual waste from AWTs - 150,237 t/y) (Figure 14).

Pet waste

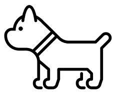


114,180 cats

2,084 t/y

148,125 dogs

18,384 t/y



Almost 270,000 pets (cats and dogs) are estimated to live in the four-case study LGAs based on the average pet ownership in Australia. It is estimated that they produce 20,466 t/y of pet waste with the majority disposed to landfill through kerbside residual bin or the four-council park and street bins. Some of the pet waste is potentially also naturally composted in the parks or within homes.

Figure 14: Estimated pet waste in Blacktown, Penrith, Bayside and Randwick councils for 2020/21.

5.3 Estimating and understanding non-residential UOW using BinTrim data

While residential FO and GO is captured in NSW through LGAs reporting to the NSW EPA, there is very little publicly available data on non-residential FO and GO. This study explores potential pathways to estimate the quantities and geospatial distribution of FO and GO arising from the non-residential sector due to this major gap in the accessible data.

Initially the study aimed to identify the quantities generated by business type categorised by ANZSIC codes (Appendix Table 8). While this captures variation in organic waste generation by business type, there is also a variation within each business type depending on other factors such as the business size. Aiming to capture that variability as well, the businesses were further analysed by the number of employees. Factors for FO and GO generation based on the business type (ANZSIC code) and business size (e.g., employing 1-19, 20-199, 200+) are developed using two approaches described in more detail in Appendix Section A.4.7.

In the first approach, data from ABS Waste Accounts (based on Australia wide waste data) was used to derive the factors. However, the business type grouping in the ABS Waste Accounts is limited to only a few ANZSIC groups. In the second approach, BinTrim data (NSW based), including complete ANZSIC group set, was used to derive the factors. The limitation of a BinTrim data set is that it is based only on the businesses that have participated in the BinTrim program.

The two approaches provide very different estimates (Figure 15). Using ABS factors, 36 kt/y of FO is estimated across the four LGAs. Using the BinTrim factors, 80 kt/y of FO is estimated. In the National Waste Report, it is reported that 1.32 Mt/y of FO was generated across the whole Australian C&I sector in 2018/19 (Pickin, et al., 2020). Considering 3% of Australian businesses are located in the study LGAs, it could be estimated that 40 kt/y FO arises from these four LGAs. This is comparable to the estimated FO using ABS factors (36 kt/y).

There is no such estimate for GO, which also differs between the two approaches (Figure 15). Considering that BinTrim data is generally visually estimated based on volume this could result in potentially high levels of uncertainty in the data. In addition, the BinTrim program aims to address the recycling issues for businesses that mostly focus on FO and not GO, which could lead to a disproportionate representation of businesses addressing FO issues as opposed to GO in the dataset. Therefore, GO data is mostly collected as a stream present in addition to FO.

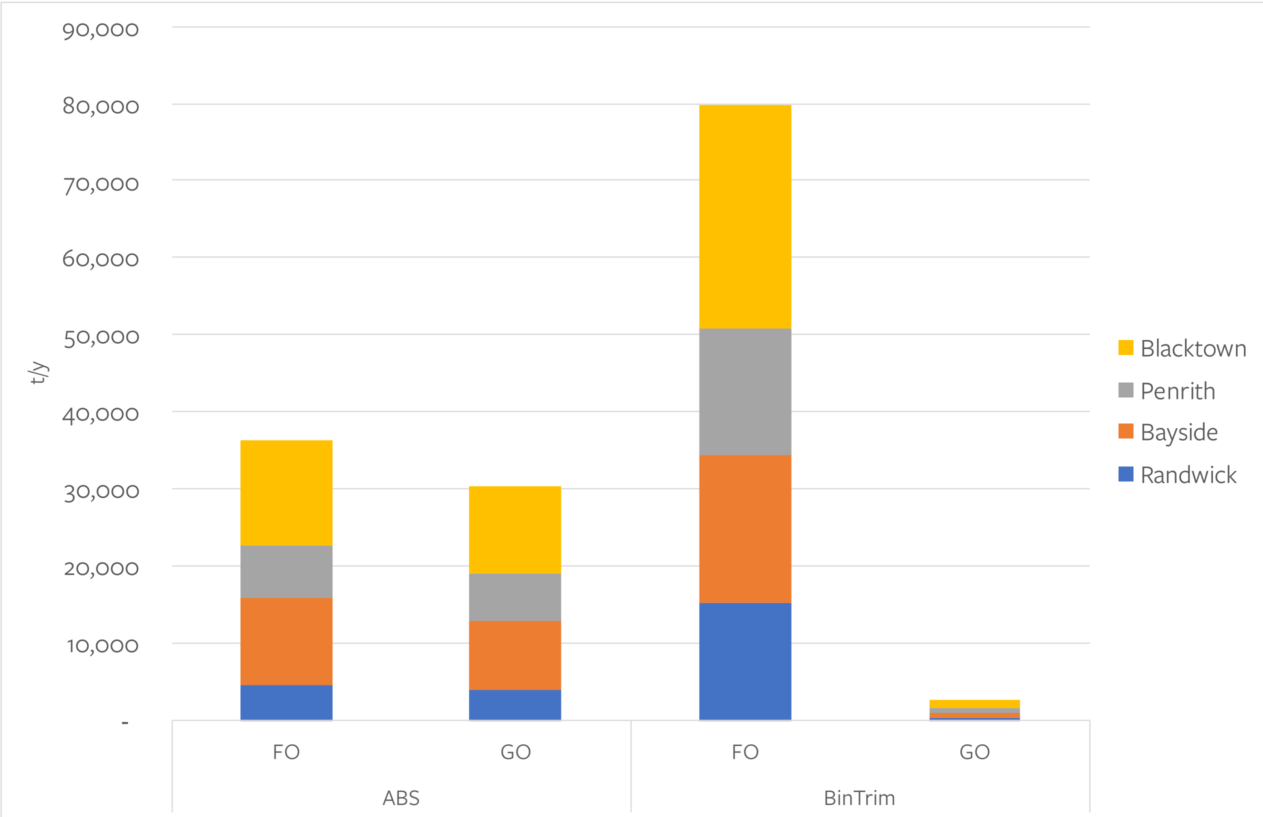


Figure 15: FO and GO in non-residential sector for 2020/21 developed using ABS factors and BinTrim factors.

To establish what is the cause for the differences between the two approaches (ABS and BinTrim), the estimated FO is further analysed for the ANZSIC code groupings that are in common (Appendix Table 8). In Figure 16, estimated FO values for the six common ANZSIC code groups show that in some categories the quantities estimated with the ABS method are higher than quantities estimated with the BinTrim method, but for others it is the opposite. However, in most cases, except for the *Public administration and safety* grouping, the proportional distribution between LGAs within each of the groupings is consistent regardless of the method used. As the BinTrim method includes all ANZSIC groups, FO arising from these sectors is analysed further.

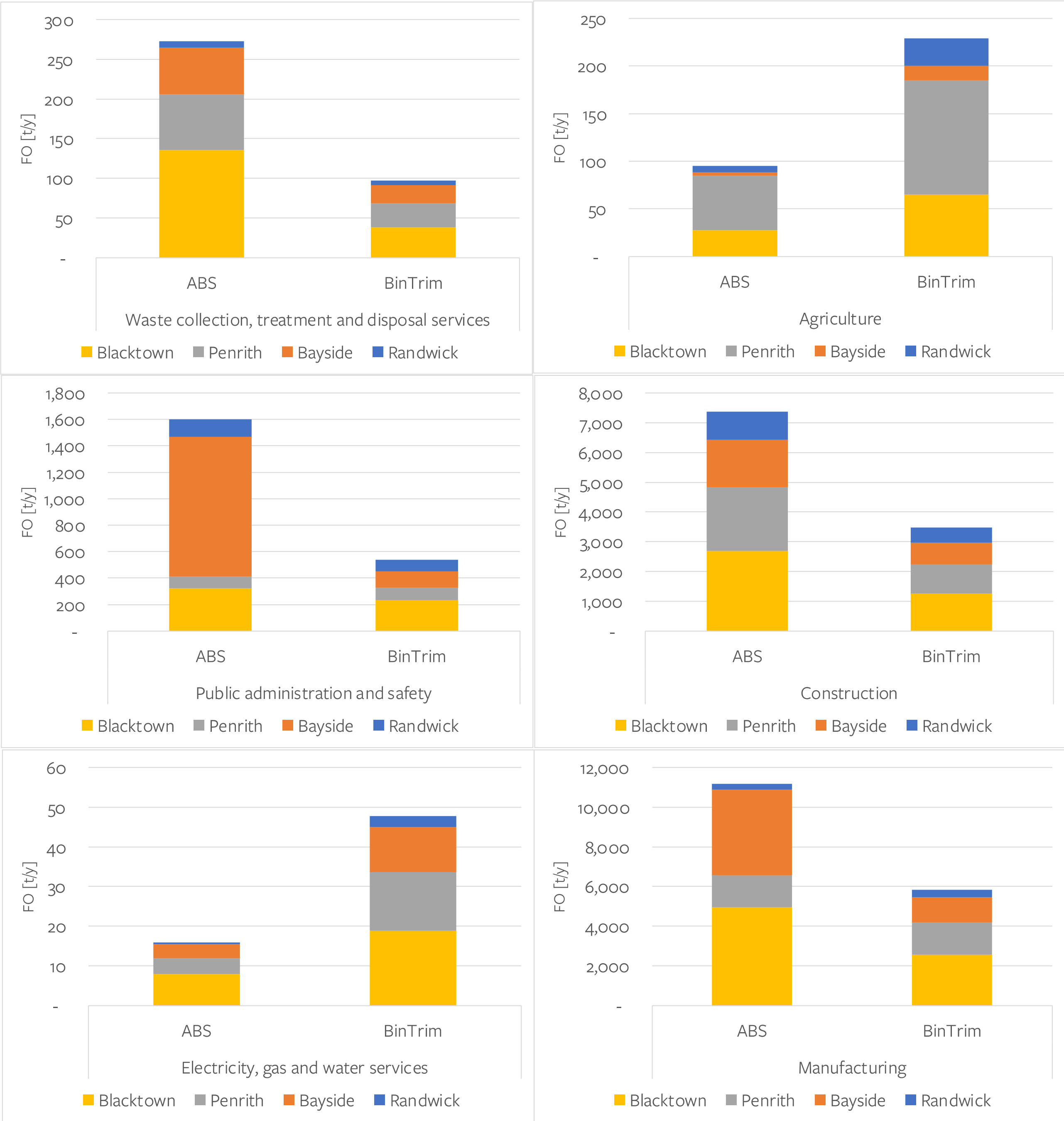


Figure 16: Estimated FO [t/y] using ABS and BinTrim factors by LGAs for common ANZSIC groupings for 2020/21.

Figure 17 shows estimated FO (using BinTrim factors) and the number of businesses from which that FO is generated within the ANZSIC groupings for the four LGAs. These graphs indicate that even though some of the ANZSIC groups have the largest number of businesses (e.g., *Construction* and *Professional, Scientific & Technical Services*), they are not the largest source of FO generation. On the other hand, as anticipated, the largest source of FO appears to be from the *Accommodation and Food Services* group, despite the number of businesses representing that group not being the largest.

A	Agriculture, Forestry and Fishing	K	Financial and Insurance Services
B	Mining	L	Rental, Hiring and Real Estate Services
C	Manufacturing	M	Professional, Scientific and Technical Services
D	Electricity, Gas, Water and Waste Services	N	Administrative and Support Services
E	Construction	O	Public Administration and Safety
F	Wholesale Trade	P	Education and Training
G	Retail Trade	Q	Health Care and Social Assistance
H	Accommodation and Food Services	R	Arts and Recreation Services
I	Transport, Postal and Warehousing	S	Other Services
J	Information Media and Telecommunications		

Figure 17: Estimated FO [t/y] in 2020/21 by LGA (using BinTrim factors) for ANZSIC groups (primary axis, green bars) and number of businesses for ANZSIC groups (secondary axis, grey line).

Food Innovations Australian Limited (FIAL) estimates that more than 50% of FO generated in hospitality and institutions in Australia is disposed to landfill (FIAL, 2021). This includes the *Accommodation and Food Services* group, for which is estimated (using the BinTrim method) that it produces 40% of the FO in the study LGAs (Figure 17), even though only 7% of all businesses are in this group. The second largest generation of FO for the study LGAs arises from the *Retail trade* group (10%), also representing about 7% of all businesses. FIAL (FIAL, 2021) estimates that more than 60% of FO generated in the retail is disposed to landfill.

Based on this analysis there is a significant opportunity within these sectors to divert FO that is currently disposed to landfill.

6 Bioenergy potential

This section presents results on the potential bioenergy generation via AD for all FO, GO, wastewater and FOG generated in the study area. It also highlights some of the limitations of using such streams including advised co-digestion feedstock composition limitations.

6.1 Baseline bioenergy potential estimates for 2020/21

Figure 18 shows the hypothetical potential electricity generation from bioenergy in the study area by LGA and organic feedstock for 2020/21. The biomethane potential for each of the feedstocks is shown in Table 16. For this study, it is assumed that biogas generated from the AD process would be combusted in a generic gas turbine system for the generation of electricity, at a conversion efficiency of 34% (Lou, et al., 2013). Overall, there is approximately 126,000 MWh of electricity generation potential in the study area from the investigated feedstocks, which also include the GO stream which would not be normally digested in an AD but is shown here due to the estimated comparable quantities to FO.

The Blacktown LGA is estimated to have the highest bioenergy potential, at approximately 52,600 MWh/y, with significant contribution from GO to this potential. Although a successful co-digestion outcome of FO with GO has been shown in the literature (e.g., Biesdorf Borth, et al., 2022 and Perin, et al., 2020), it was only observed at limited GO conditions. They observed that the highest conversion efficiency is obtained where the GO feedstock is limited to a composition of maximum 20% GO (Perin, et al., 2020). Furthermore, the GO used in these studies predominantly consisted of grass clippings. The composition of Blacktown GO has not been assessed as part of this study but considering many SUD properties include large grass areas GO could potentially include significant amounts of grass clippings. However, the Blacktown LGA does not have a separate GO collection service, meaning that additional collection of GO would be required to harness this bioenergy generation potential.

Randwick LGA is estimated to have the lowest bioenergy generation potential. This could be attributed to the relatively small size of Randwick compared to other LGAs included in the study area.

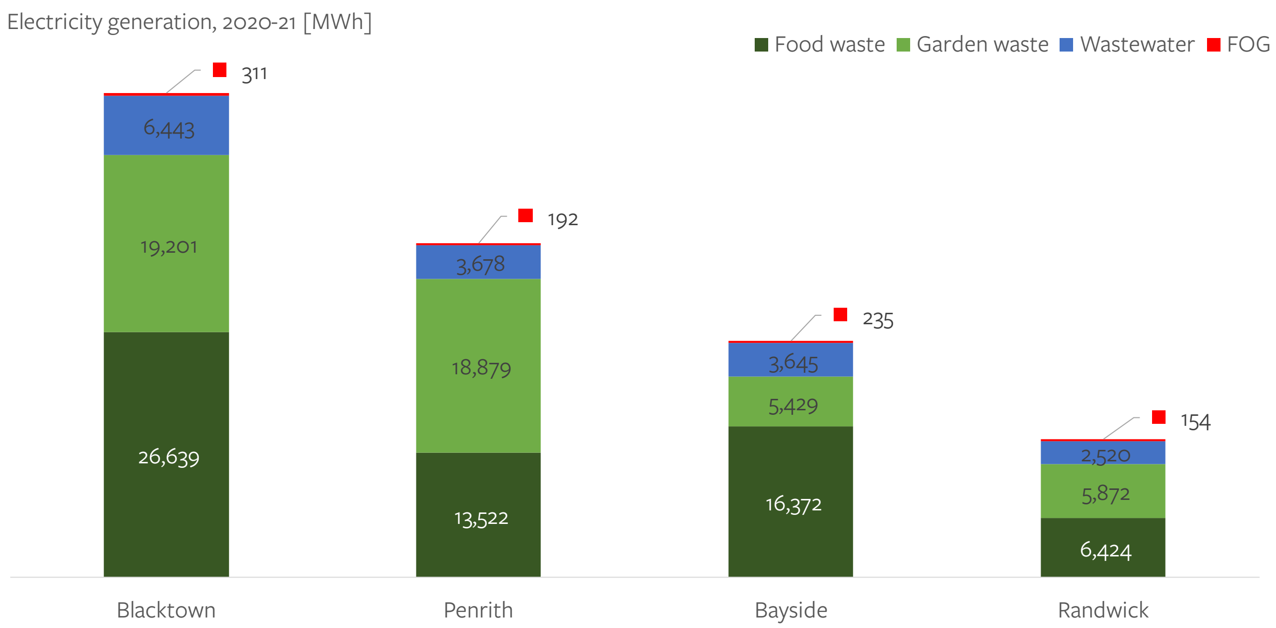


Figure 18: Estimated potential electricity generation from bioenergy in the study area for 2020/21

Figure 19 shows the breakdown of bioenergy potential by source of organic waste feedstock. Penrith is the only LGA where GO is estimated to contribute the most to the energy potential. It is important to note again, that GO is not an ideal digestion feedstock, due to the lignocellulosic characteristics of GO as mentioned above. Hence the bioenergy potential of the GO shown in Figure 19 would be curtailed and the bioenergy in practice significantly less than that shown.

FO from both residential and non-residential sources is estimated to contribute the most to the bioenergy potential across the LGAs – between 37% to 64% (Figure 19). Bayside LGA which has a high proportion of MUDs-type dwellings has the highest proportion of residential FO. FO however is not currently separately collected in any of the LGAs in the study area. FO is collected in combination with GO as FOGO collection in both Penrith and Randwick LGAs. While FO is collected in Randwick across all households, in Penrith it is only collected in SUDs. Nevertheless, FOGO is not a suitable feedstock for AD due to the high proportion (~80%) of garden waste in the FOGO stream. In addition, if FOGO consists predominantly of ligneous wooden branches and sticks and not cellulous grass clippings, it would not be suitable for AD at all. Collecting and keeping FO as a separate stream for subsequent treatment alone or with other UOW in ideal compositional mixes would provide the highest opportunity to harness bioenergy potential.

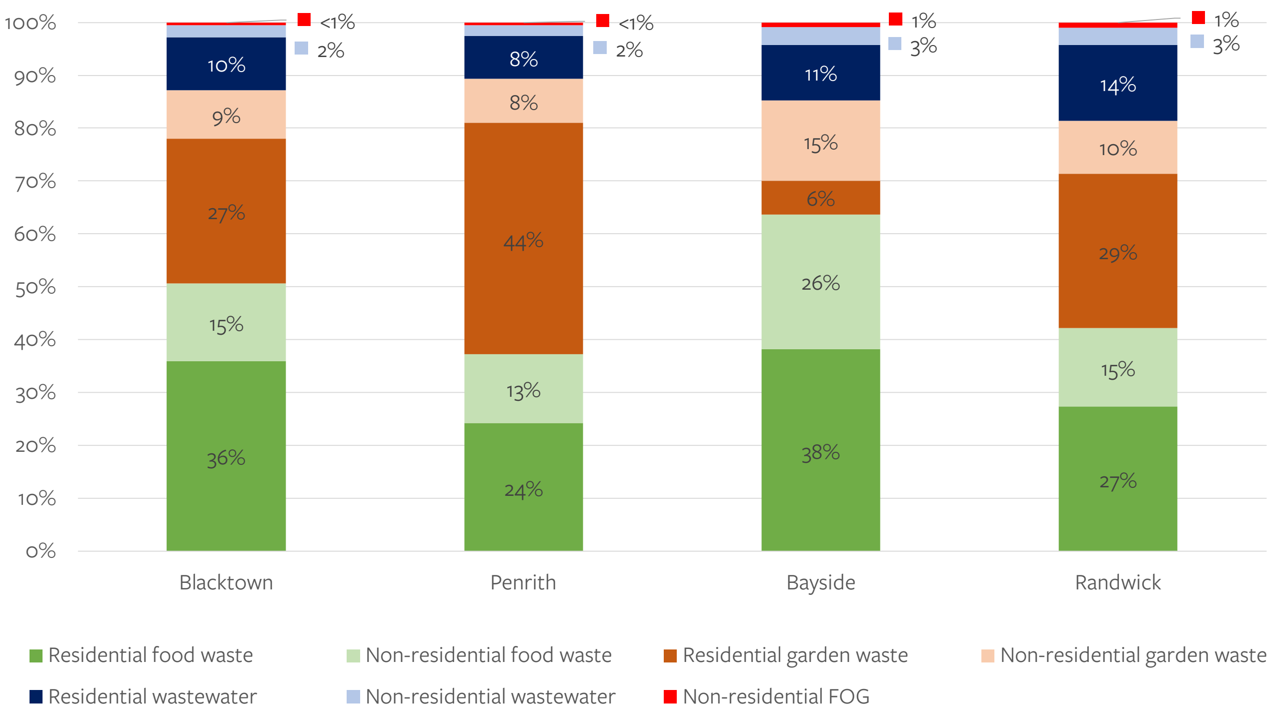


Figure 19: Breakdown of potential bioenergy generation by source of organic waste feedstock.

The estimated contribution of wastewater to bioenergy potential ranges from approximately 10% in Penrith, to 18% in Randwick, with non-residential wastewater estimated to contribute only 2-3% across the LGAs. The contribution of FOG is estimated to be small at around 1%, which is expected given that a relatively small volume of FOG generation has been reported compared to the other organic waste streams in the study area. Although the opportunity to use FOG for bioenergy potential appears to be small, it provides far greater sustainability and circular economy outcomes as opposed to other current end uses such as soil injection. Further, several WWTPs around the world have successfully achieved energy self-sufficiency by utilising FOG in co-digestion with sewage (Shen, et al., 2015) due to the positive impact on the overall bioenergy potential when it is co-digested with sewage. However, there are limitations in operating conditions (e.g., temperature, C/N ratio, suspension pH, micronutrients and other parameters). To achieve optimal conditions for co-digestion, addition of only a few percent of FOG, by volume, is required (Salama, et al., 2019).

Complete results of the estimated bioenergy potentials by LGA and by source are tabulated in Appendix Section A.5.1. Figure 20 shows the estimated energy potential for the UOW streams studied and their contribution to the estimated energy generation based on the organic quantities generated in 2020/21. FO has a slightly higher energy potential compared to GO and although the stream quantities are similar, FO's contribution to energy generation is higher. Also noticeable is significantly lower energy generation contribution from sewage despite being by far the biggest quantity. Sewage is predominantly water with less than one percent of organic matter. On the other hand, despite the extremely small quantities of FOG, it's contribution to energy generation is notable and as indicated above can be highly beneficial in low compositional concentrations in AD co-digestion.

It should be noted that these are theoretical values and in practice energy generation from AD varies significantly based on the composition of feedstock and operating conditions. For example, for feedstocks high in lignin (as found in GO), their degradation under anaerobic conditions would be hardly noticeable. Even cellulose (normally present in plants) would take several weeks to degrade under anaerobic conditions. On the other hand, hemicellulose, fat, and protein (components found in FO and sewage) would anaerobically degrade within a few days; with low molecular sugars, volatile fatty acids and alcohols degrading within few hours (Steffen, et al., 1998).

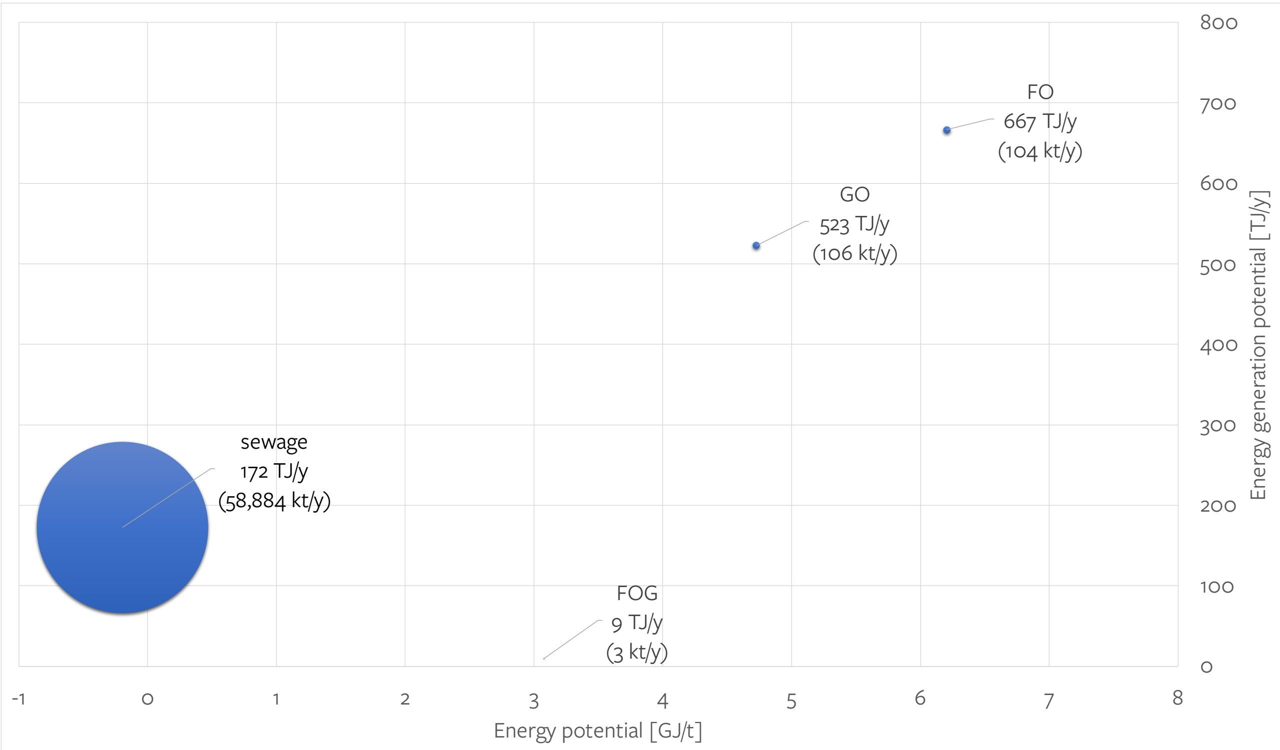


Figure 20: Estimated UOW energy generation potential for 2020/21 for UOW streams graphed against their energy potential.

The estimated UOW generation quantities in the study LGAs are significantly higher than the available capacity at the upgraded WWTPs (Table 4). Although, the estimated UOW generation is unlikely to be fully separated at source even if a separate FO, GO or FOGO service is available. It is consistently observed that LGAs that have a FO, GO or FOGO service still find around 50% of FO or GO remain in the residual bin (Rawtec, 2020). Nevertheless, as it can be seen in Table 4, the capacity of the WWTPs could be filled by combining FO from the non-residential and residential sectors from the adjacent councils. The available capacity in the three

WWTPs could meet 20% of the AD infrastructure gap for Sydney identified in the NSW Waste and Sustainable Materials Strategy Infrastructure needs report (DPIE, 2021b).

Table 4: Estimated capacity for FO intake for the case study WWTPs compared to the FO generated in the adjacent LGAs.

WWTP	Capacity [t/y]	Council	FO in MUDs [t/y]	FO in SUDs [t/y]	Non-residential FO [t/y]	Total
Malabar	19,345	Bayside	8,738	7,842	11,762	28,342
		Randwick	4,056	2,447	4,867	11,370
St Mary's	11,680	Penrith	2,869	11,642	7,814	22,325
Riverstone	21,535	Blacktown	5,475	25,743	14,644	45,862

6.2 Spatial distribution of bioenergy potential

Figure 21 and Figure 22 show the spatial distribution of the estimated bioenergy potential over the study area. These figures show the bioenergy generation potential (measured in MWh) for each SA1 across all LGAs, based on the estimated SA1 organic waste arising. Note that these figures do not include bioenergy potential for the trade waste stream (exclusion of trade waste is discussed in Appendix Section A.4.9). These figures show that bioenergy potential is generally dispersed across the study area, corresponding to SA1s with large numbers of dwellings, and/or large numbers of businesses.

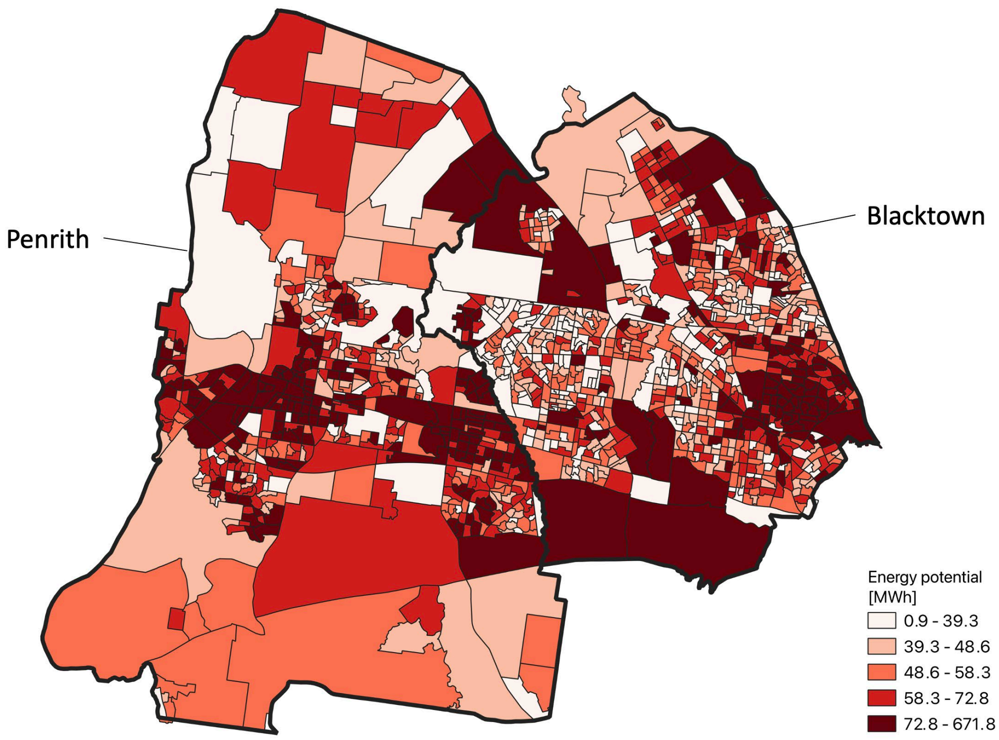


Figure 21: Spatial distribution of bioenergy potential for LGA group 1 (Blacktown and Penrith)

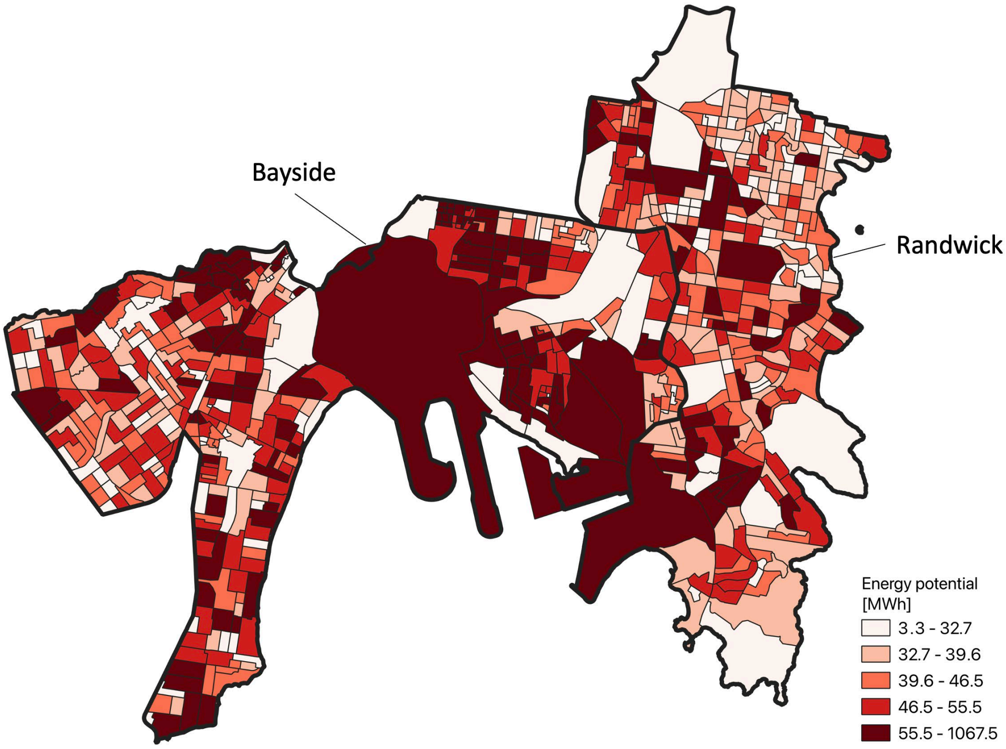


Figure 22: Spatial distribution of bioenergy potential for LGA group 2 (Bayside and Randwick)

Data in Figure 21 and Figure 22 could be useful in a planning context, as it highlights areas of intense waste generation and feedstock availability. Data in Figure 21 and Figure 22 is further examined by performing a 'hot-spot' analysis, which helps to identify statistically significant hot-spots, or clusters of intense feedstock availability. This analysis is performed by calculating the G_i^* statistic on bioenergy potential for each SA1, which is a local measure of whether or not data in a spatial unit (e.g., SA1) belongs to a statistically significant cluster of high (or low) values (Gatis and Ord, 1992). An SA1 is considered to be a hot-spot if it has a high value of bioenergy potential, and is surrounded by neighbours with high values as well. This approach is utilised to identify areas that may be prioritised for future feedstock collection for the deployment of AD in the study area.

Figure 23 and Figure 24 illustrate results of this analysis. Three hot-spots of feedstock availability are identified, these are along the central area of the Penrith LGA; on the south-eastern portion of the Blacktown LGA; and the eastern portion of the Bayside LGA. While no hot-spot is identified in Randwick, SA1s in Randwick have contributed to the hot-spot identified in the Bayside LGA. For the Penrith hot-spot, the identified area corresponds with the main residential area of the LGA. For the Blacktown hot-spot, this area corresponds with the residential suburbs of Seven Hills and Toongabbie. The Bayside hot-spot corresponds primarily with non-residential land use in the suburb of Botany, including the Botany port terminal.

Hot-spots identified in Figure 23 and Figure 24 are further examined in Figure 25, which shows the distribution of feedstock and the bioenergy generation potential in the Blacktown, Penrith and Bayside hot-spots. The hot-spot located in Penrith LGA has the greatest bioenergy generation potential — expected given the size of the identified hot-spot — at approximately 20,800 MWh. This is followed by the hot-spot located in Blacktown LGA, at approximately 12,300 MWh of bioenergy electricity potential. Residential sources of feedstock including residential wastewater are significant contributors to overall bioenergy potential, contributing to 74% and 62% of the total bioenergy potential in the Penrith and Blacktown hot-spots respectively. Non-residential sourced feedstock has made a larger contribution in the Bayside hot-spot, contributing 78% to total bioenergy potential. This is expected, given the density of non-residential land use located within the identified Bayside hot-spot.

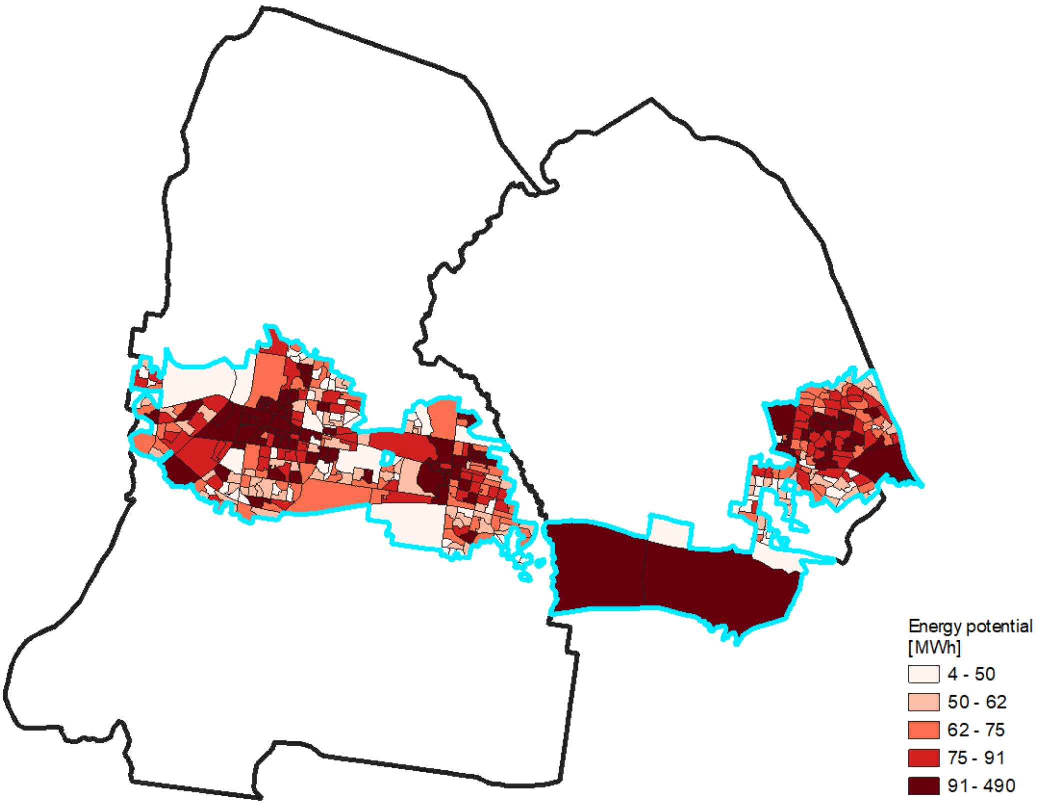


Figure 23: Identified hot-spots of feedstock availability in LGA group 1 (Blacktown and Penrith).

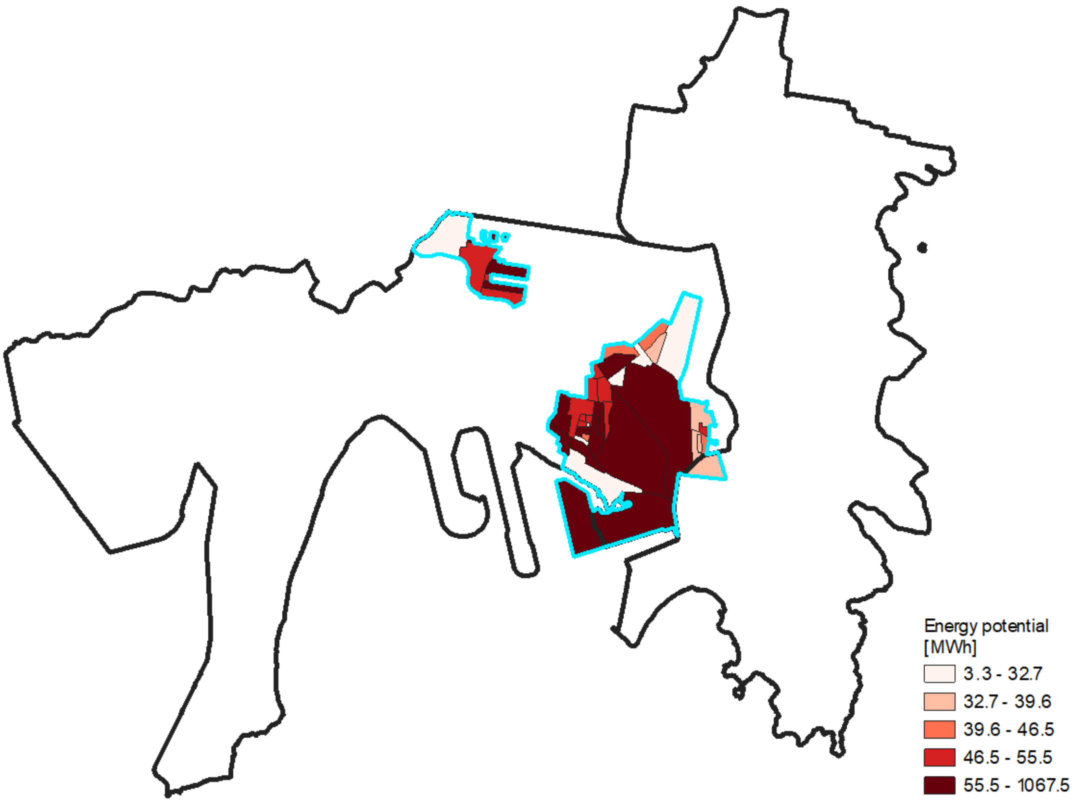


Figure 24: Identified hot-spots of feedstock availability for LGA group 2 (Bayside and Randwick).

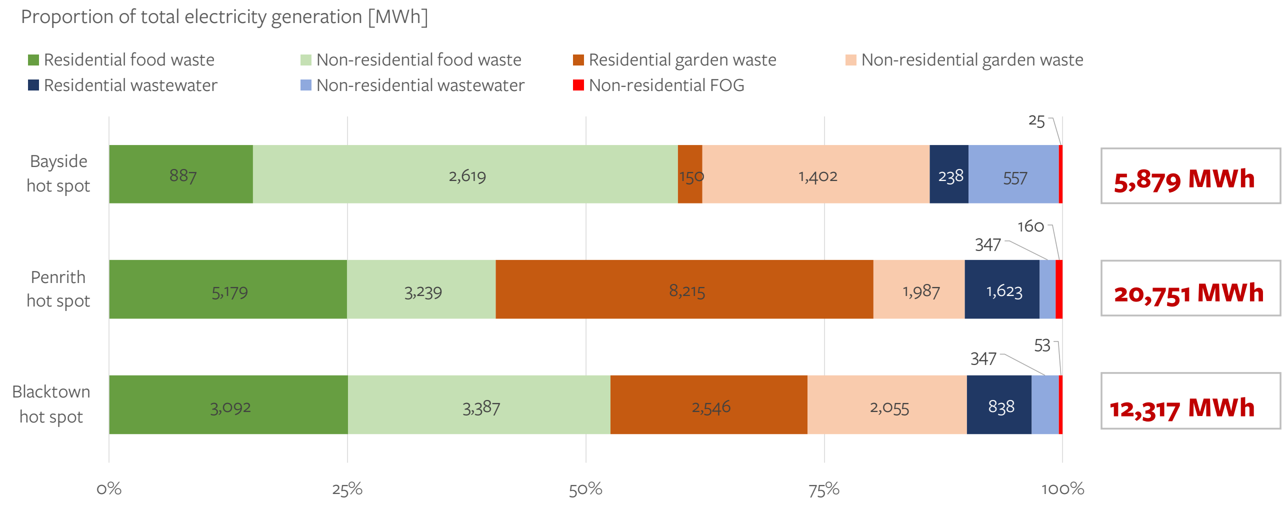


Figure 25: Distribution of bioenergy potential by organic waste feedstock source in each identified hot-spot in Figure 23 and Figure 24.

GO makes a significant contribution to overall bioenergy potential in these three hot-spots, which is consistent with findings presented in Figure 18. It is important to note again however, that GO is not an ideal feedstock for bioenergy conversion via AD, hence the energy contribution would be less than the potential identified if restricted within the AD process. Therefore, hot-spot analysis is performed excluding GO feedstock from UOW arisings from both residential and non-residential sectors. Results of this analysis are illustrated in Figure 26 (B) and Figure 27 (B) and plotted against the analysis results including GO streams (Figure 26 (A) and Figure 27 (A)).

When GO is excluded a much smaller hot-spot is observed in Penrith LGA clustered around Penrith shopping district where a concentration of MUDs is also found. On the other hand, two broader hot-spots are observed in Blacktown (Figure 26 (B)) around Blacktown and Seven Hills town centres and Western Parkland City industrial park area. Looking at Bayside and Randwick (Figure 27 (B)), the hot-spot is expanding from predominantly the non-residential area around the airport and including Eastgardens, to Port Botany industrial area in Randwick. An additional hot-spot is formed when GO is excluded around Mascot in a high-density MUDs area that includes hotels as well.

Maps in Figure 26 and Figure 27 illustrate how feedstock distribution could inform planning decisions in designing infrastructure for collection and processing of UOWs.

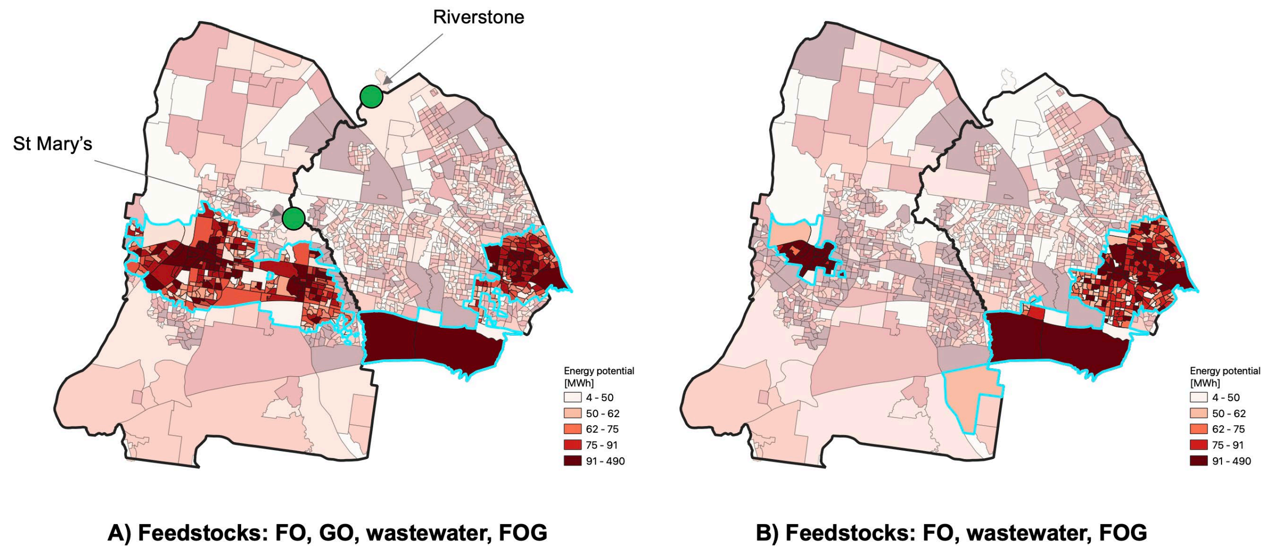


Figure 26: Identified hot-spots for energy potential based on residential and non-residential sector feedstock availability, including (A) and excluding (B) GO in LGA group 1 (Blacktown and Penrith).

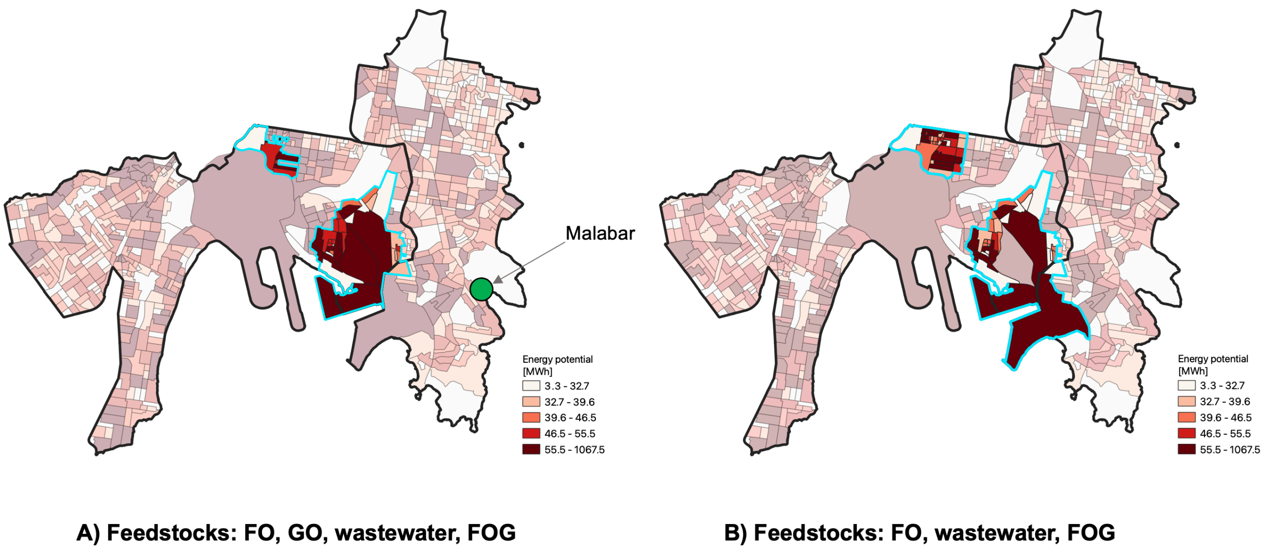


Figure 27: Identified hot-spots for energy potential based on residential and non-residential sector feedstock availability, including (A) and excluding (B) GO in LGA group 1 (Blacktown and Penrith).

This section estimated the hypothetical bioenergy potential based on each individual stream. However, the selected WWTPs for this case study (Table 2) have a limited capacity for the external feedstock (approximately 52,560 t/y). Assuming only FO is used for co-digestion, it is estimated that up to 62,957 MWh/y of potential energy could be generated. Biogas generated from co-digestion by capturing a just a proportion of this FO bioenergy potential could therefore provide a significant contribution to the renewable energy generation for the case study LGAs, especially considering that current estimated generation from solar energy is 27,740 MWh/y (Table 3).

7 Projections to 2030/31

Projections of organic waste and bioenergy generation potential to 2030/31 is estimated for each LGA in the study area. Only potential bioenergy generation from residential sources is projected to 2030/31 due to the unavailability and uncertainty in the non-residential data. This paucity in data requires further investigation.

7.1 Demographics projections

To estimate future bioenergy generation potential, projections of the number of households in each LGA by 2030/31 is obtained from the NSW Department of Planning and Environment (NSW DPE, 2022). This data reports only the projected number of households, not projections by dwelling type. It is therefore assumed that for Bayside and Randwick LGAs, any new dwellings established between 2020/21 and 2030/31 would be MUDs, with the expected number of SUDs in 2030/31 being equal to the number in 2020/21. For Penrith and Blacktown, it is assumed that the proportion of MUDs and SUDs to total dwellings would remain constant from 2020/21 to 2030/31. This assumption is made given land release in Penrith and Blacktown would enable further growth in SUDs, whereas land limitations in Bayside and Randwick would prevent further growth of SUDs. Figure 28 shows projected MUDs, SUDs (and total dwellings) in 2030/31 for the study LGAs. Data is tabulated in the Appendix Table 23.

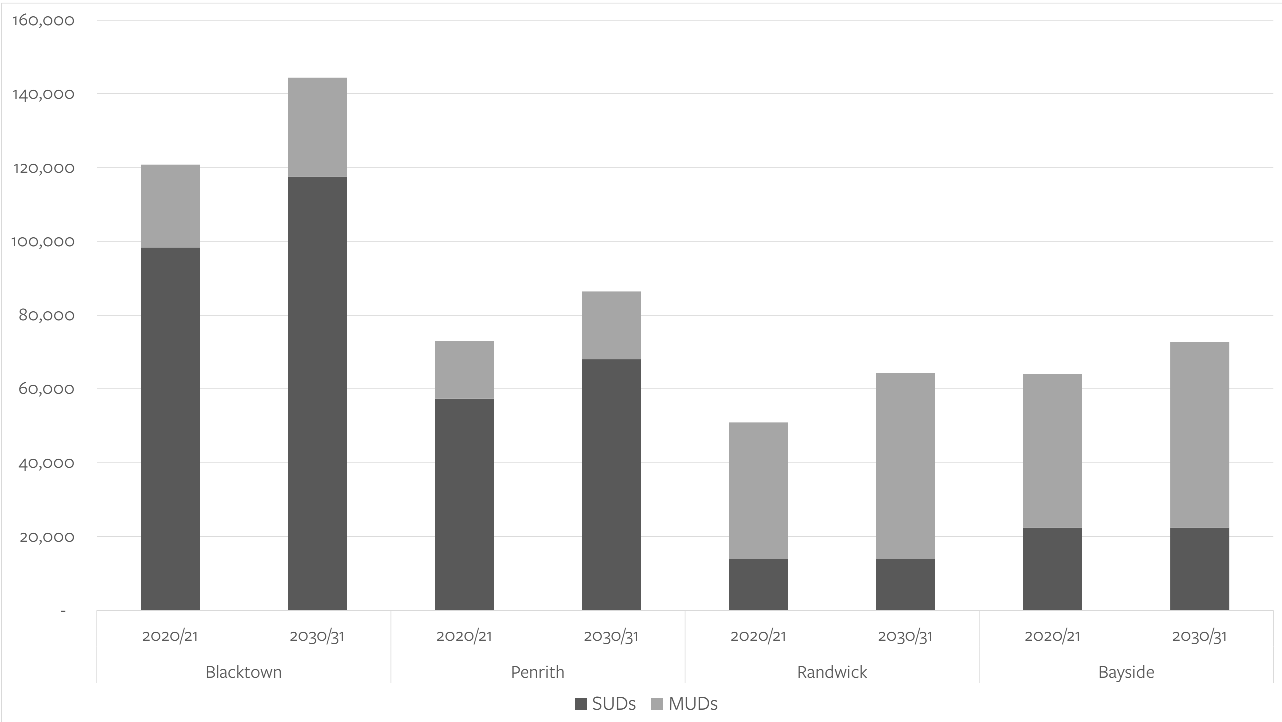


Figure 28: Dwelling projections from 2020/21 to 2030/31 by LGA.

7.2 Residential urban organic waste projections

Bioenergy potential in 2030/31 is estimated assuming constant per-dwelling generation rates for each residential organic waste stream, based on MUDs and SUDs dwelling numbers and organic waste generation in 2020/21. These rates are then applied to the projected dwelling numbers in 2030/31. Figure 29 shows estimated projected organic waste generation in 2030/31 for each residential waste stream, compared to generation in 2020/21.

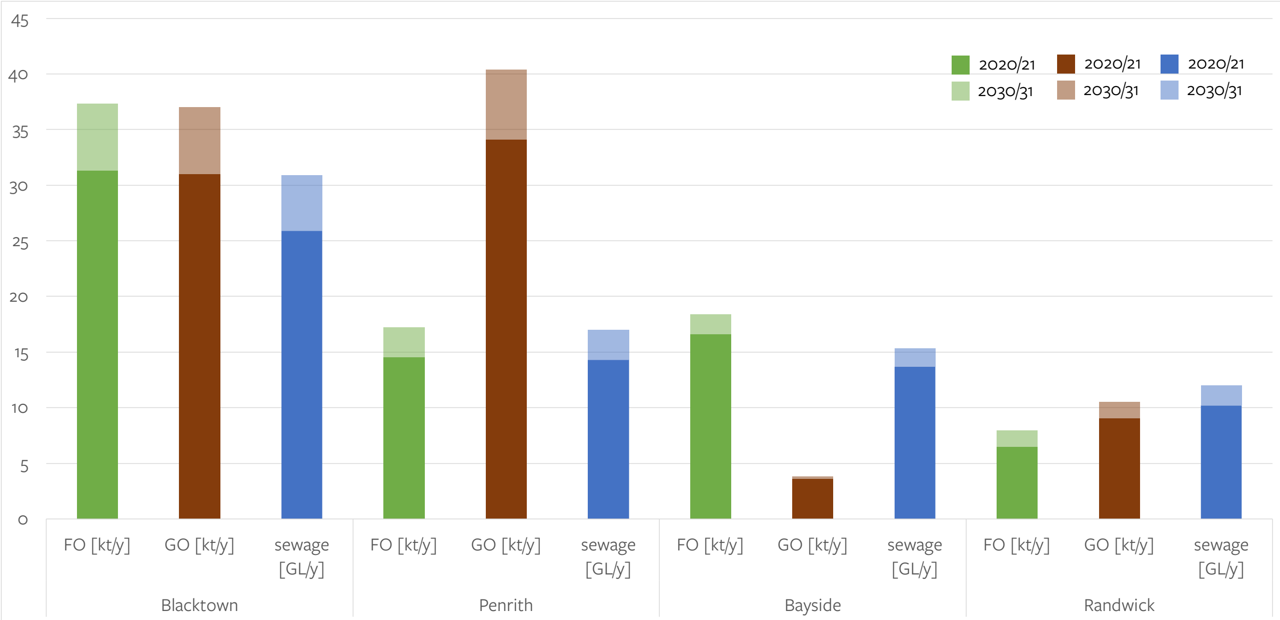


Figure 29: Organic waste generation projections by LGA for 2030/31

It should be noted however that the National Food Waste strategy sets a target of halving FO generation by 2030 (AUS, 2017). Should this target be achieved, FO generation would be about 40% less than modelled (40% reduction in Blacktown, 41% reduction in Penrith, 45% reduction in Bayside and 39% reduction in Randwick). However, considering that food waste generation has started to increase again (5% in the last year) after an initial decline of 10% from 2017 till 2020 (Pickin, et al., 2020), it is very likely that the target of halving food waste generation will not be met by 2030.

7.3 Projected bioenergy generation potential

The projected bioenergy potential is estimated following the approach outlined in Appendix Section A.5.1. Figure 30 shows projected electricity generation potential from bioenergy from residential sources for each LGA in 2020/21 and 2030/31. Overall bioenergy potential from residential sources in the study area, including GO, is projected to increase from an estimated 90,800 MWh in 2020/21 to 112,400 MWh in 2030/31; an increase of approximately 24%. This increase is the greatest in Randwick (28%), which will see the largest increase in population across the LGAs in scope.

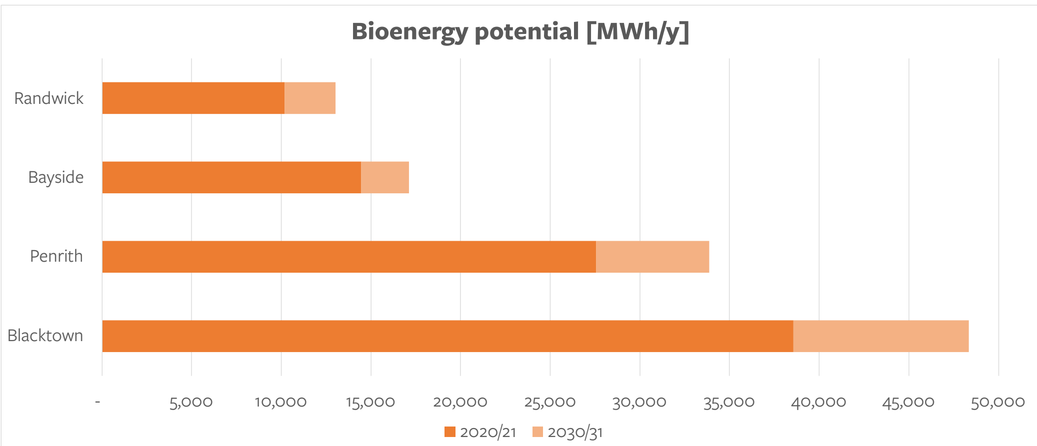


Figure 30: Projected bioenergy generation potential (MWh) by LGA for 2030/31

8 Discussion

To meet the net zero and waste strategy targets (Appendix Table 5), diversion of UOW from landfills to higher order circular economy processing of organic waste is needed. Based on the estimated bioenergy potential, biogas generated from the investigated UOW streams could provide a significant renewable energy source for the study LGAs. The analysis identified that the three selected WWTP could provide as much as 20% of the identified AD infrastructure capacity gap for Sydney by 2030 (e.g., over 50 kt/y capacity, the equivalent of EarthPower capacity), with more potential organics available from the investigated streams than the WWTPs can treat. Using the available capacity at the three WWTPs could provide renewable energy, reduce waste currently passing to landfill, reduce GHG impacts and provide multiple cross-sectoral policy benefits. It could also save on some of the identified AD infrastructure capital costs needed as well as provide access to a processing opportunity in a relative short timeframe, as well as existing AD expertise. Whilst the inclusion of additional organic feed stocks could affect the capacity of WWTP AD and bring forward future upgrades this needs to be weighed against the potential cross-sectoral benefits. Such scenario analysis and costs and benefits analysis should be considered in a larger future study.

Feedstocks for co-digestion

For the WWTPs, accepting external feedstocks for co-digestion with sewage, offers a possibility to become energy self-sufficient due to the enhanced biogas generation from the AD co-digestion process. On the other hand, co-location of external UOW streams with sewage at WWTPs creates an opportunity for the WWTPs to become circular economy hubs offering more localised solutions for various UOW streams.

However, to achieve these benefits modification of UOW management is required as well as cross sectoral collaboration between the waste, wastewater, and energy sectors. This also requires careful consideration in the decision-making process within each of the sectors to avoid locking in solutions that could disable the cross sectoral collaboration and therefore halt the transition to a circular economy. As highlighted in this study the AD feedstock suitability is determined by the feedstock collection and source separation method applied in the waste management sector. For example, if residential FO is collected through FOGO, it makes this stream hard to process through AD. The four LGAs analysed in this study all currently offer different kerbside waste collection services, ranging from FO being collected only through the residual bin to FO collected through the FOGO bin, and with or without separate GO collection (Table 3).

The literature reviewed in this study highlights that most of the FO that is landfilled occurs at the consumer level, specifically households, institutions and hospitality. There is however high paucity and uncertainty in data, especially in the non-residential waste data. While the methodology developed in this study to estimate the quantities of UOW generated in the non-residential sector provides insights as to where the UOW might occur, geographically as well as by industry type, the uncertainty in calibrating such data remains. Even the organics data presented in the National Waste Report states high uncertainty (Pickin, et al., 2020).

This study aims to identify UOW hot-spots, which could assist identifying where the greatest volumes of UOW are generated and illustrate how such information could be useful in informing decisions on the rollout of separate organics collections, waste transfer station's placement and UOW processing options planning.

AD feedstock combination options, specifically for co-digestion, AD digestion process options, including pre-treatment and biogas applications, were workshopped with the project partners and IRG (Appendix Section A.8.) Workshop participants identified non-residential FO and FOG as suitable feedstocks to be considered for co-digestion at WWTPs, a higher circular economy opportunity than current practice of disposal to landfill or

FOG's soil injection. Although residential FO is also suitable feedstock for co-digestion, specifically due to the identified large quantities, the current direction of waste policy, stipulating its collection through FOGO, is making this stream potentially difficult to access and/or unsuitable. However, the FO from the growing MUDs sector, which has little if any GO, could more easily be collected and directed towards AD. There is also a growing competition for the FO resource via alternative treatment and processing pathways to be considered (e.g., private industry FOGO composting, on-site AD, on-site dehydrators, macerators with soil injection and even FO bioconversion with black soldier flies). In addition, there are barriers such as often lengthy and limiting contractual agreements (already in place for potential feedstocks, many not expiring until the second half of this decade in the residential sector) and a lack of regulations for the by-products generated from AD (e.g., digestate or biosolids application). The potential to introduce contamination due to multiple streams and inconsistency in the feedstock composition and supply (e.g., seasonal variability[5]) also adds complexity which potentially requires installation of additional pre-processing infrastructure.

UOW processing options

While this study estimates generation of energy via AD specifically, there are alternative processes and technologies that could be deployed to generate energy from UOW, especially for GO. Alternative processing technologies, such as pyrolysis and gasification were suggested by workshop participants to address the contamination from UOW carried into the digestate. Hydrolysis of FO was also suggested by workshop participants as a potential processing option generating biohydrogen, biomethane or other valuable organic compounds. European countries which have employed waste to energy plants to deal with the residual waste, including UOW are moving away from thermal processes for organics and are mandating source separation for FO (Waste Framework directive Article 22[6] and Article 10[7] (EEB).

However, addressing emerging barriers as well as challenges from management of multiple stakeholders and sectoral collaboration were identified as a need for further study. While this study focuses specifically on co-digestion, exploring further co-location opportunity including associated costs was also highlighted in the workshops. Furthermore, benchmarking with the approaches taken by other jurisdictions should also be considered in the future study.

Biogas application

Biogas generated through AD has several possible applications, each requiring different levels of treatment (e.g., gas cleaning) and consequently potential installation of additional infrastructure. While generated biogas is most commonly used at WWTPs for heating and electricity requirements, some WWTPs have modified their operations to generate surplus biogas that could also be used as a replacement of fossil (natural) gas or as a transport fuel. In addition, bio-methane could replace fossil-based methane in industrial chemical processes. These internal and external biogas applications were recommended by workshop participants to be explored in further studies including identifying opportunities for accreditation supporting renewable energy transition with biogas, as well as financial viability in the energy market.

[5] FO profile and quantities change seasonally due to seasonal impacts of growing food and resulting food waste, as well as challenges due to storage and heat. Therefore, AD operation would be impacted by changing profile and quantity of feedstock.

[6] Obligatory separate collection of biowaste.

[7] Biowaste shall not be burned or landfilled.

AD by-products (Bio-CO_2, digestate/biosolids)

The AD process generates in addition to methane other by-products that could provide additional benefits and play a role in enabling a transition to a circular economy. For example, Bio-CO_2, a biogas component could have an application in other industries, such as greenhouse horticulture and beverage manufacturing. Digestate is also a by-product of AD and can be used in multiple applications. 'Whole digestate' can be applied to land as biofertiliser or composted first before being applied to land. Another pathway of application to land is to separate the liquid and solid fraction of the digestate. Alternatively elemental fertilisers (N, P, K) can be extracted and thus provide a more targeted application.

Currently, the estimated 9.6 kt/y of biosolids resulting from the sewage stream in the study LGAs already have a beneficial application as biosolids applied to land in regional NSW. However, Sydney Water bears the cost of this without a revenue opportunity (Jazbec, et al., 2022). Biosolids may contain macronutrients, such as nitrogen, phosphorus, potassium and sulphur, and micronutrients such as copper, zinc, calcium, magnesium, iron, boron, molybdenum and manganese (DSEWPC, 2012) – all essential for plant growth. As the biosolids may also contain traces of synthetic organic compounds and metals, including arsenic, cadmium, chromium, lead, mercury, nickel and selenium, they are thoroughly regulated, and their use could be potentially limited in some cases. However, the majority of biosolids (83%) in Australia have beneficial use and more than 70% of biosolids were used for agricultural application in 2021 (AWA, 2022). For the study LGAs, it is estimated that biosolids generated in 2020/21 contained 386 t of nitrogen and 241 t of phosphorous. If sold at the fertiliser market price this would generate a substantial revenue for Sydney Water. Contribution to production of biosolids due to the co-digestion of food waste with sewage is negligible as food waste contains a higher fraction of volatile solids, which are also more biodegradable than wastewater sludge (Nghiem, et al., 2017).

UOW carbon footprint mitigation

Processing UOW through AD has the potential to decrease the carbon footprint of the waste and wastewater sectors. GHG emissions arising from the waste and wastewater sectors are due to fugitive methane and nitrous oxide emissions, as well as from fuel and electricity consumed through the management of waste and wastewater. A large proportion of GHG emissions in the waste sector are due to the anaerobic decomposition of organics in landfill. In the study area investigated for this project, emissions from landfilling of residential and non-residential FO for example, could result in lifetime[8] landfill gas emissions of up to 33,000 t CO_2-e per year. While not all of the solid organic waste generated in the study area in 2020/21 was disposed to landfill, harnessing the available FO generated in the area for AD could lead to emissions avoidance of up to 16,800 t CO_2-e of lifetime emissions per year. This rough estimate assumes a digestor processing 52,560 t/y of FO and does not take into consideration emissions associated with the transportation of waste; the net emissions of the digestion process itself; nor potentially avoided emissions from the replacement of fossil-fuel derived energy sources.

Cross-sectoral benefits

As outlined throughout the report, co-digestion of UOW at the WWTPs provides a wide range of benefits for the wastewater, waste and energy sectors. While accepting external UOW streams for co-digestion boosts energy generation in the wastewater sector, it also contributes to the generation of renewable energy for the energy sector. At the same time, this provides an alternative pathway for the processing of UOW and diversion

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[8] Organic waste degradation in landfills is normally calculated over the landfill lifetime. It should be noted that some landfills capture biogas either for generation of energy or flaring which would reduce the GHG estimated here.

from landfills for the waste sector. It provides agile short, medium and/or long-term AD capacity opportunities as cities such as Sydney grow, as well as an opportunity to utilise the existing AD expertise and management knowledge already within the wastewater industry. In addition, it offers an opportunity to harness the benefits of energy and nutrients at a more local scale. This contributes to achieving net zero emissions for all three sectors as well as waste avoidance and contribution to landfill diversion targets. That is, multiple cross-sectoral benefits.

9 Recommended next steps

This study quantifies various available UOW streams, their energy potential and geospatial proximity to the selected Sydney Water AD assets. An analytical and mapping framework was developed which used primarily publicly available data for the study area. This therefore allows replication for other jurisdictions in NSW and elsewhere. The inclusion of more detailed but not always publicly available data (e.g., wastewater flows, BinTrim data, etc.) allowed the evaluation of non-residential and sewage sources which is an innovative and important contribution. The geospatial aspect taken in this study is a further innovation that allows more advanced analysis including facility allocation, evaluating resource availability, and assessing transport and collection options.

The following next steps are identified for potential follow-on RACE projects:

- Use of data in further analysis
  - In addition to the available desktop data, use the additional data provided from potential project partners and government agencies.
- Further analysis of the UOW streams
  - Obtaining data for the non-residential sector (C&I) was challenging and the methods employed to estimate the quantities show inconsistent results. Further analysis and stakeholder consultations to obtain current and projection data are recommended.
  - Literature review indicates that most of the FO generated in the institutions' sector is currently disposed to landfill. Diversion of UOW from landfill for this sector would therefore provide a significant benefit. It is recommended to expand the analysis to include this stream and to engage stakeholders from the institutional sector (e.g., education, prisons, public service) to obtain information and data.
- Feedstock collection methods
  - This study assumes that the UOW would be collected and transported by trucks. However alternative collection methods through piping network or drop off points have been successfully applied internationally. It is recommended that future studies evaluate these options in addition to collection by trucks.
  - Also recommended is appraisal of the optimal transport distances for treatment of various UOW streams for different transport types.
- Methane and energy generation potential of co-digestion feedstocks.
  - The estimated energy generation potentials are estimated for UOW streams individually, therefore not considering the enhanced benefits of multiple streams co-digestion. It is recommended that such combinations are considered in further research.
  - Assessment of different feedstock options, combinations, and proportions based on the literature and stakeholders identified opportunities and concerns should be further analysed.
- Options for collection and processing of UOW steams
  - Quantifying all UOW streams (including UCO, trade waste, pet waste, etc.) and finding the best collection and processing options based on cost and benefit analysis is recommended.
  - Evaluate impact of options based on GHG emission reduction for whole value chain using a life cycle approach e.g., transport, treatment, fugitive emissions etc.
  - Evaluation of trade-offs of different options through multi criteria analysis should be investigated.
- UOW market analysis for the Greater Sydney area
  - Identify circular economy market opportunities for UOWs and roadblocks, such as feedstock fluctuations, stream contaminations, and other logistics barriers as well as regulation barriers.

- Identify opportunities for WWTP utilities to work with regulators (e.g., EPA and IPART) on the impacts of biosolids utilisation in the case of co-digestion of sewage with other organic streams.

- Develop business case for co-digestion of UOW
  - Considering fee structure, optimal collection and processing options, infrastructure needs (transfer stations, pre-treatment, post-treatment, storage), location, risk mitigation plan.
  - Identify barriers related to existing contracts and assets, policy, approval pathways, commercial and technological limitations.
- Stakeholders along the value chain
  - Expand the stakeholder analysis to include broader engagement in the study.
  - Identify stakeholder priorities and enable dialogue for alignment of objectives along the value chain.
  - Identify knowledge pathways to enable broad cross-sectoral knowledge sharing.
  - Link to other related agencies e.g., SSROC, NSROC, Resilient Sydney etc.
- Benchmarking with international best practice
  - Identify the best practice from international case studies.

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APPENDIX

A.1. Relevant strategies and policies

Table 5 summarises relevant strategies and policies in Australia, States and Territory in relation to net zero targets and for organic waste management.

Table 5: Australian States' strategies for net zero targets and organic waste disposal to landfill.

State/ Territory	Strategy/Action Plan	Targets
Global	Global Methane Pledge (GMP, 2021)	• Cutting at least 30% of anthropogenic methane emissions by 2030 from 2020 levels
National	National food waste strategy: Halving Australia's food waste by 2030 (AUS, 2017) National waste policy, Action plan (AUS, 2019) Australia legislates emissions reduction targets – media release (AUS PM, 2022)	• Halve food waste in Australia by 2030 • Halve the amount of organic waste sent to landfill for disposal by 2030 • Net zero emissions by 2050 • Australia's emissions reduction target 43% by 2030
NSW	NSW Waste and Sustainable Materials Strategy 2041, Stage 1: 2021-2027 (DPIE, 2021a) Net Zero Plan, Stage 1: 2020-2030 (DPIE, 2020)	• Halve the amount of organic waste sent to landfill by 2030 • Net zero emissions from organic waste by 2030 • Net zero emissions by 2050
VIC	Cutting Victoria's emissions 2021-2025 (DELWP, 2021b) Victoria's climate change strategy (DELWP, 2021a) Media release – Victoria makes gains in race to net zero with new targets (CC, 2022)	• Halve food and organic waste going to landfill between 2020 and 2030 (interim target of 20% reduction by 2025) • Based on 2005 levels, 28-33% reduction by 2025, 45-50% reduction by 2030, net zero by 2050 • Updated targets in October 2022: 75-80% reduction by 2035 (based on 2005 levels) and net zero by 2045
QLD	Queensland Organics Strategy 2022-2032, A strategy to improve the management of organic materials along the organics supply and consumption chain (DES, 2022) Pathways to a clean growth economy, Queensland Climate Transition Strategy (DEHP , 2020)	• Divert 80% of organic material generated from landfill • Achieve minimum organic recycling rate of 70% • Net zero by 2050, interim target: at least 30% reduction in emissions on 2005 levels by 2030
SA	Supporting the circular economy, South Australia's waste strategy 2020-2025 (SA, 2020) Valuing our food waste, South Australia's strategy to reduce food waste 2020-2025 (SA, 2021)	• By 2025, South Australia to adopt kerbside bin systems that optimise diversion of organics and recyclables and enable delivery of the MSW 75% diversion target • Supporting National Waste policy of halving the amount of organic waste sent to landfill for disposal by 2030 • Supporting National Food Waste Strategy 50% reduction target by 2030 by promoting food waste prevention measures

State/ Territory	Strategy/Action Plan	Targets
	South Australian Government Climate Change Action Plan 2021-2025 (DEW, 2020)	• Net zero by 2050, more than 50% reduction based on 2005 by 2030
WA	Waste Avoidance and Resource Recovery Strategy 2030, Western Australia's Waste Strategy (DWER) Western Australian Climate Policy (DWER, 2020) Government Emissions Interim Target (WA, 2022)	• No clear target for organics • Net zero by 2050, including bioenergy from biomass • Interim target for WA government emissions – 80% below 2020 by 2030
TAS	Draft Waste Action Plan (DPIPWE, 2019) Tasmanian Government Legislated new emission reduction target (DSG, n.d.) Tasmania: Net Zero by 2030, Emissions Pathway Review Summary (Point Advisory, 2021)	• Reduce volume of organic waste sent to landfill by 25% by 2025 and 50% by 2030 • Net zero by 2030
ACT	Waste Management Strategy 2011-2025 (ACT, 2011) ACT Climate Change Strategy (ACT, 2019)	• No organics specific targets • Net zero by 2045 • Interim target of cutting emissions by 50-60% (from 1990) by 2025
NT	Northern Territory Circular Economy Strategy 2022-2027 (NT, 2022) Northern Territory Climate Change Response: Towards 2050 (NT, 2020)	• No target, identified need to prevent food waste and organics going to landfill • Net zero emissions by 2050

A.2. Waste hierarchy

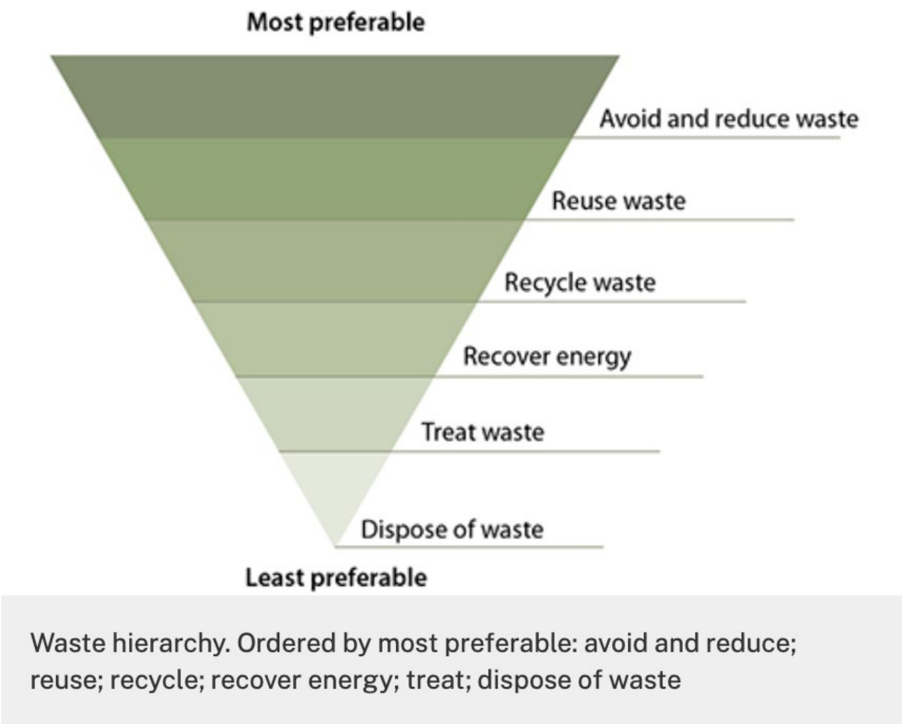


Figure 31: Waste Hierarchy. Source NSW EPA (NSW EPA, 2022c)

A.3. Kerbside (residential) waste service in Greater Sydney Area

Table 6: Kerbside waste service in residential sector in Greater Sydney Area by 2022.

District	LGA	GO	FO	FOGO	Recycling	Paper	Residual
Western City	Blue Mountains	✓			✓		✓
	Camden	✓			✓		✓
	Campbelltown	✓			✓		✓
	Fairfield				✓		✓
	Hawkesbury	✓			✓		✓
	Liverpool	✓			✓		✓
	Penrith			✓	✓		✓
	Wollondilly	✓			✓		✓
Central City	Blacktown				✓		✓
	Cumberland	✓			✓		✓
	Paramatta	✓			✓		✓
	The Hills	✓			✓		✓
Eastern City District	Bayside				✓		✓
	Burwood	✓			✓		✓
	City of Canada Bay	✓			✓		✓
	City of Sydney	✓	✓(1)		✓		✓
	Inner West	✓	✓(2)		✓		✓
	Randwick			✓	✓		✓
	Streatfield	✓			✓		✓
	Waverley	✓			✓	✓	✓
	Woollahra	✓			✓		✓
North District	City of Ryde	✓			✓		✓
	Hornsby	✓			✓		✓
	Hunters Hill	✓			✓	✓	✓
	Ku-ring-gai	✓			✓	✓	✓
	Lane Cove	✓			✓	✓	✓
	Mosman	✓			✓		✓
	North Sydney		✓(1)		✓		✓
	Northern Beaches	✓			✓	✓	✓
	Willoughby	✓			✓		✓
South District	Canterbury-Bankstown	✓	✓(1)		✓		✓
	Georges River	✓			✓		✓
	Southerland	✓			✓		✓
TOTAL		27	4	2	33	5	33

(1) FO trial

(2) FO in MUDs only

A.4. Methodology

This section describes the methodology applied in the research and forms a basis for the data collection and analysis framework. It identifies the data needed and describes the calculation methods applied in estimating the results presented in this study.

A.4.1 Data Sources

Table 7 summarises the data sources of the data used to perform the analysis. Included are notes on challenges, reliability and access for each of the data type.

Table 7: Data type and sources used to perform the analysis.

Data type required	Data sources	Notes on challenges, reliability, and access
Geospatial data	ABS	Data at the *Statistical area 1* (SA1) and *Statistical area 2* (SA2) levels were utilised. These are geographical units, with approximate populations of 400 people for SA1s, and 10,000 people for SA2.
Household type data	ABS	Data on household type (e.g., detached dwellings, apartments, etc) are publicly available from ABS. The highest resolution data on dwelling types available is at the SA1 scale. We distinguish between single-unit dwellings (SUDs) and multi-unit dwellings (MUDs).
Business types, employment data	ABS	Publicly available data on locations and size of businesses in the study area is limited. In our approach, we use the number of employees as a proxy for business size. Data on the number of businesses by industry type and number of employees within a range (e.g., 1-19, 19-200, 200+) is available at the SA2 scale.
Residential food waste (FO)	WARR reporting Waste audits	Data on residential FO is derived from WARR reports, which includes quantities of mixed waste and FOGO waste collected by council area. To estimate FO generation, audit reports (e.g., Rawtec, 2020 and APC, 2019) were used to estimate the proportion of food in the mixed and FOGO streams. The APC data was also used to estimate waste generation rates separately for SUDs and MUDs.
Residential garden organics (GO)	WARR reporting Waste audits	Data on residential garden waste is derived from WARR reports. Audit reports (e.g., Rawtec, 2020 and APC, 2019) were used to estimate the proportion of garden waste in FOGO collections, and for separate SUDs and MUDs generation rates.
Residential sewage	WWTPs (e.g., Sydney Water)	Data on wastewater discharge for SUDs and MUDs were provided by Sydney Water. This data included potable water consumption, with discharge calculated from consumption by applying sewage discharge factors, also supplied by Sydney Water. Discharge factors used were: SUDs discharge factor: 0.74 MUDs discharge factor: 0.72
Pet waste	Literature	Studies on ownership statistics for pets (specifically dogs and cats) were used to estimate the average number of pets in the four LGAs that were included in the study. Daily generation of faeces for an average dog or cat was estimated based on the reported data in literature. These values were estimated to determine the size of the steam for comparison.
Non-residential food waste (FO)	ABS BinTrim	There is no readily available data of non-residential FO broken down by business type category or by location. To estimate the quantities of the FO generated by business type, we used multiple sources. ABS data was used to determine the distribution (based on ANZSIC) and size (number of employees) of the businesses. Non-employing businesses were excluded. FO generation factors by business type (ANZSIC) and size (by number of employees) were determined using the data provided by ABS Waste Accounts (ABS, 2020) and counts of Australian Businesses (ABS, 2021a). As the breakdown by business types is limited (Table 11), we attempted to use BinTrim data to develop the factors. However, BinTrim data is visually estimated and limited to only the businesses that have undergone the BinTrim program. Some of the BinTrim assessors have not collected all the information, allocated wrong entries making data patchy and unreliable.

Data type required	Data sources	Notes on challenges, reliability, and access
Non-residential garden organics (GO)	ABS BinTrim	Estimated as above using the same data sources (non-residential FO but for GO).
Non-residential fats, oil and greases (FOG)	WWTPs (e.g., Sydney Water)	Data on grease trap collections were provided by Sydney Water, and include detail on the estimated total volume extracted from grease traps in the study area, and estimated volume of settled solids.
Trade waste	WWTPs (e.g., Sydney Water)	Trade waste data was provided by Sydney Water, including total quantities of trade waste discharge, and discharge characteristics (e.g., BOD, suspended solids, etc.). This data was not utilised in calculations for bioenergy potential, as the data is highly uncertain (e.g., unclear what is actual discharge versus what is allotted through trade waste licensing).
Non-residential sewage	WWTPs (e.g., Sydney Water)	Data on non-residential potable water consumption and discharge were provided by Sydney Water. A discharge factor of 0.78 was used to estimate non-residential discharge from potable water consumption.
WWTP characteristics	WWTPs (e.g., Sydney Water) Literature	WWTP characteristics applied in the analysis were supplied by Sydney Water. Any information gaps were filled from literature sources as described below.
Bioenergy potential	Literature, WWTPs pilot studies (e.g., Sydney Water)	Bioenergy potential for the range of feedstocks considered were estimated based on data in the literature (see Appendix 11.4.10). Data is limited on the characteristics of feedstocks from a local context, specific to the study area. Bioenergy potential was estimated based on assumed mesophilic anaerobic mono-digestion for each organic waste feedstock, using parameters from the literature.
Renewable energy	Renewable Energy Installations	Energy generation from renewable sources (solar, wind, hydro and biomass) was collected for the four LGAs for small scale generation (RET, 2022b) and large-scale generation (RET, 2022a).
Future projections	NSW Department of Planning and Environment	Data on anticipated number of dwellings in 2030/31 were based on the *2022 NSW Population, Housing and Implied Dwelling Projections*, available from the NSW Department of Planning and Environment. The projected number of total dwellings by LGA for 2030/31 were taken from this data. It was assumed that the proportion of dwellings that are SUDs/MUDs would be fixed for Blacktown and Penrith (e.g., new dwelling growth will be a mix of SUDs and MUDs). For Randwick and Bayside, it was assumed all new dwellings would by MUDs.

A.4.2 ANZSIC codes

Table 8 lists the Australian and New Zealand Standard Industrial Classification (ANZSIC). ANZSIC is a standard classification developed by the Australian Bureau of Statistics to use in Australia and New Zealand for the analysis of industry statistics. In the Waste Accounts the ANZSIC codes are grouped into eight groups as listed in Table 8.

Table 8: ANZSIC list and grouping of ANZSIC codes used in analysis.

	ANZSIC	Groupings in analysis
A	Agriculture, Forestry and Fishing	Agriculture
		All Other Industries
B	Mining	Mining
C	Manufacturing	Manufacturing
D	Electricity, Gas, Water and Waste Services	Electricity, Gas and Waste services

		Waste Collection, Treatment and Disposal Services
E	Construction	Construction
F	Wholesale Trade	All Other Industries
G	Retail Trade	All Other Industries
H	Accommodation and Food Services	All Other Industries
I	Transport, Postal and Warehousing	All Other Industries
J	Information Media and Telecommunications	All Other Industries
K	Financial and Insurance Services	All Other Industries
L	Rental, Hiring and Real Estate Services	All Other Industries
M	Professional, Scientific and Technical Services	All Other Industries
N	Administrative and Support Services	All Other Industries
O	Public Administration and Safety	Public Administration and Safety
P	Education and Training	All Other Industries
Q	Health Care and Social Assistance	All Other Industries
R	Arts and Recreation Services	All Other Industries
S	Other Services	All Other Industries

A.4.3 Number of businesses by ANZSIC code and number of employees

In Table 9 number of businesses for Randwick, Bayside, Blacktown and Penrith study LGAs are categorised within each of the ANZSIC code and grouped by the number of employees.

Table 9: Distribution of number of businesses within each employee category in Randwick, Bayside, Blacktown and Penrith LGAs.

	ANZSIC	Randwick				
		No-emp	1-19	20-199	200+	Total
A	Agriculture, Forestry and Fishing	59	24	0	0	81
B	Mining	4	4	0	0	11
C	Manufacturing	147	116	8	0	266
D	Electricity, Gas, Water and Waste Services	14	12	0	0	24
E	Construction	1054	1062	20	0	2138
F	Wholesale Trade	173	164	11	0	348
G	Retail Trade	358	321	13	3	694
H	Accommodation and Food Services	144	426	57	0	626
I	Transport, Postal and Warehousing	648	129	16	3	787
J	Information Media and Telecommunications	135	130	3	0	266
K	Financial and Insurance Services	374	194	0	0	569
L	Rental, Hiring and Real Estate Services	1536	285	3	0	1826
M	Professional, Scientific and Technical Services	1370	1032	13	0	2415
N	Administrative and Support Services	286	286	13	3	593
O	Public Administration and Safety	16	25	6	0	46
P	Education and Training	167	136	15	3	317
Q	Health Care and Social Assistance	865	537	22	0	1429
R	Arts and Recreation Services	193	117	6	0	322
S	Other Services	252	281	5	0	538

		Bayside				
		No-emp	1-19	20-199	200+	Total
A	Agriculture, Forestry and Fishing	38	13	0	0	53
B	Mining	3	4	0	0	9
C	Manufacturing	243	320	36	5	608
D	Electricity, Gas, Water and Waste Services	21	34	3	0	55
E	Construction	1619	1515	50	0	3184
F	Wholesale Trade	332	384	45	3	763
G	Retail Trade	572	529	34	0	1132
H	Accommodation and Food Services	218	559	36	4	816
I	Transport, Postal and Warehousing	2150	510	32	5	2703
J	Information Media and Telecommunications	106	68	0	0	180
K	Financial and Insurance Services	427	202	6	0	636
L	Rental, Hiring and Real Estate Services	1882	304	11	0	2205
M	Professional, Scientific and Technical Services	1115	959	43	0	2114
N	Administrative and Support Services	572	391	33	0	1002
O	Public Administration and Safety	30	36	4	3	82
P	Education and Training	136	104	9	0	246
Q	Health Care and Social Assistance	403	368	23	0	794
R	Arts and Recreation Services	142	82	3	0	225
S	Other Services	378	467	7	0	859

		Blacktown				
		No-emp	1-19	20-199	200+	Total
A	Agriculture, Forestry and Fishing	101	43	3	0	144
B	Mining	6	6	0	0	15
C	Manufacturing	431	625	88	3	1148
D	Electricity, Gas, Water and Waste Services	41	36	9	0	84
E	Construction	2354	2560	83	0	4996
F	Wholesale Trade	467	647	96	0	1209
G	Retail Trade	787	988	47	0	1811
H	Accommodation and Food Services	246	705	58	4	1004
I	Transport, Postal and Warehousing	4461	1112	24	3	5599
J	Information Media and Telecommunications	129	92	0	0	222
K	Financial and Insurance Services	472	281	3	0	758
L	Rental, Hiring and Real Estate Services	1544	353	11	0	1910
M	Professional, Scientific and Technical Services	1469	1543	18	0	3029
N	Administrative and Support Services	903	620	37	3	1564
O	Public Administration and Safety	76	71	14	0	157
P	Education and Training	199	185	16	0	399
Q	Health Care and Social Assistance	732	690	40	0	1461
R	Arts and Recreation Services	143	109	9	0	261
S	Other Services	627	801	15	0	1446

		Penrith				
		No-emp	1-19	20-199	200+	Total
A	Agriculture, Forestry and Fishing	177	73	7	0	258
B	Mining	8	9	4	0	18
C	Manufacturing	288	435	46	0	778
D	Electricity, Gas, Water and Waste Services	30	49	3	0	76
E	Construction	1631	2032	65	0	3724
F	Wholesale Trade	218	265	31	0	510
G	Retail Trade	379	453	27	0	855
H	Accommodation and Food Services	96	342	33	3	470
I	Transport, Postal and Warehousing	1122	697	12	0	1831
J	Information Media and Telecommunications	60	35	0	0	98
K	Financial and Insurance Services	253	195	5	0	446
L	Rental, Hiring and Real Estate Services	1351	202	11	0	1568
M	Professional, Scientific and Technical Services	674	683	16	0	1374
N	Administrative and Support Services	369	309	23	3	706
O	Public Administration and Safety	24	37	3	0	65
P	Education and Training	101	103	16	0	222
Q	Health Care and Social Assistance	390	404	35	0	832
R	Arts and Recreation Services	93	96	6	0	195
S	Other Services	412	570	0	0	981

A.4.4 Calculation of residential food and garden organic waste arisings

To calculate residential waste arisings at the SA1 level, first per-dwelling waste generation rates are estimated for each LGA in the study areas. For this, council-reported waste collection data for 2020/21 (NSW EPA, 2022b) for the mixed stream, and the garden and FOGO streams is used, along with total LGA dwelling counts from (ABS, 2022). A per-dwelling generation rate is first calculated for each LGA by dividing waste generation for each stream, by total number of dwellings. Kerbside audit data obtained from Blacktown council, as well as data from kerbside audits conducted for SSROC (APC, 2019), are then used to estimate specific SUDs and MUDs generation rates, from the per-dwelling generation rate estimates. This is performed through optimisation, with constraints such that the ratio between the estimated SUDs and MUDs generation rates are the same as those found in the kerbside data, and that total estimated waste generation matches the WARR data. Table 10 shows these estimated waste generation rates. SA1 level waste generation is then estimated for each waste stream by multiplying the generation rate estimates in the table, with the number of SUDs and MUDs dwellings in SA1s across each council area.

Table 10: Estimated waste generation for 2020/21 per waste stream (mixed, GO, FOGO), household type (SUDs and MUDs) for Blacktown, Penrith, Bayside and Randwick LGAs.

LGA	Mixed waste stream		GO stream		FOGO stream		TOTAL	
	SUDs rate [kg/hh]	MUDs rate [kg/hh]	SUDs rate [kg/hh]	MUDs rate [kg/hh]	SUDs rate [kg/hh]	MUDs rate [kg/hh]	SUDs rate [kg/hh]	MUDs rate [kg/hh]
Blacktown	973.64	910.29	n/a	n/a	n/a	n/a	**973.64**	**910.64**
Penrith	474.77	442.93	n/a	n/a	563.83	502.20	**1038.6**	**945.13**
Bayside	556.83	932.50	66.76	12.48	n/a	n/a	**623.59**	**944.98**
Randwick[a]	693.32	427.94	463.36	76.95	252.12	155.62	**1408.8**	**660.51**

[a]4,345 households were reported to have FOGO collection, and 4,899 households were reported to have GO collection in the *NSW Waste and Resource Recovery* data (NSW EPA, 2022)

A.4.5 Calculation of sewage volumes in residential and non-residential sectors

For the residential wastewater, data provided by Sydney Water included potable water consumption and sewage discharge for each mesh block in the study area. Mesh blocks are the smallest spatial unit used by ABS and are part of the Australian Statistical Geography Standard (ABS, 2021b). Residential wastewater is aggregated to the SA1 level by determining which SA1 each mesh black was located in. This same operation is applied for non-residential wastewater.

A.4.6 Calculation of non-residential food waste and garden organic waste arisings

Non-residential organic waste arisings are estimated using data from ABS describing the number of businesses by industry group with employees within a certain range (e.g., no employees, 1-19, 20-199, and 200+). This data is available at the SA2 level, which correspond to areas with a population of approximately 10,000. For our analysis, numbers of businesses by type are disaggregated to the SA1 level, by apportioning the number of businesses in each SA2 evenly to the underlying SA1s contained within each SA2. To estimate FO and GO arisings from businesses, waste generation factors by industry type are estimated based on the ABS Waste Accounts (ABS, 2020) – amount of waste stream generation by sectors – and Counts of Australian Businesses (ABS, 2021a) – breakdown of businesses by each business type (ANZSIC) and number of employees (e.g., non-employing, 10-19, 20-199 and 200+). These factors are applied to the number of businesses grouped by employee numbers in each SA1. These factors are shown in Table 11.

Table 11: FO and GO factors based on business type and size (by number of employees).

	Food waste [tonnes/number of businesses/years]							
	Waste collection, treatment and disposal services	**Agriculture**	**Mining**	**Manufacturing**	**Electricity, gas, water and water services**	**Constructio n**	**Public administration and safety**	**All other industrie s**
1-19 employees	0.97	0.32	0.35	1.83	0.11	0.65	0.95	0.29
20-199 employees	18.65	6.07	6.67	35.22	2.2	12.47	18.23	5.51
200+ employees	323.84	105.42	115.83	611.5	38.21	216.49	316.57	95.72
Garden waste [tonnes/number of businesses/years]								
1-19 employees	4.07	0.27	1.24	0.98	0.48	0.73	0.8	0.24
20-199 employees	78.12	5.1	23.77	18.93	9.22	14	15.31	4.63
200+ employees	1356.34	88.52	412.71	328.58	160.05	242.98	265.84	80.38

A.4.7 Calculation of non-residential food waste and garden organic waste arisings using BinTrim data

Non-residential FO and GO are also estimated using factors derived from the BinTrim data as this data set provides a full breakdown by ANZSIC codes, unlike the ABS derived factors which only considers 7 sectors and subsectors (Table 8).

The BinTrim program is a NSW business recycling program that engages with businesses improving their waste management practices by providing free waste assessments leading to an action plan and provides up to $50,000 in funding for the eligible recycling equipment. The program has engaged with 38,000 businesses so far diverting over 260,000 tonnes of waste from landfill with an average 15% increase in recycling rate for the participating businesses (NSW EPA, 2022a). The program collects, through the assessment process, data on: the type of businesses (by ANZSIC code - Table 8); number of employees (1-19, 20-199, 200+); and visually estimated generation volumes of all waste streams (t/y), including FO and GO, that is recycled or disposed to landfill. The dataset was used to derive factors of FO and GO waste generation by type and size of business (Table 12).

Table 12: Factors for FO and GO generation in tonnes per year depending on business type (ANZSIC) and business size (number of employees) based on the Bin Trim data.

	ANZSIC	1-19		20-199		200+	
		FO	GO	FO	GO	FO	GO
A	Agriculture, Forestry and Fishing	1.37	0.16	5.33	1,68	-	-
B	Mining	0.54	0.01	1.86	1.54	5.35	0.00
C	Manufacturing	2.87	0.04	8.26	0.13	9.22	0.00
D	Electricity, Gas, Water and Waste Services	0.70	0.03	3.53	0.57	5.95	0.03
E	Construction	0.44	0.07	1.36	0.07	2.60	0.00
F	Wholesale Trade	1.45	0.06	4.18	0.17	4.01	0.00
G	Retail Trade	2.93	0.11	7.85	0.13	7.76	0.27
H	Accommodation and Food Services	10.70	0.15	46.59	0.62	115.24	0.00
I	Transport, Postal and Warehousing	1.32	0.06	4.14	0.29	2.22	0.00
J	Information Media and Telecommunications	1.01	0.00	7.72	0.06	7.06	0.00
K	Financial and Insurance Services	0.76	0.01	4.01	0.00	23.19	0.18
L	Rental, Hiring and Real Estate Services	2.96	0.06	12.32	0.01	15.89	0.00
M	Professional, Scientific and Technical Services	1.33	0.04	5.66	0.02	17.03	0.00
N	Administrative and Support Services	1.31	0.07	4.15	0.09	29.10	0.00
O	Public Administration and Safety	1.82	0.27	7.48	0.31	9.63	2.01
P	Education and Training	2.54	0.22	8.61	0.50	14.99	2.27
Q	Health Care and Social Assistance	1.23	0.07	19.26	0.57	33.61	0.00
R	Arts and Recreation Services	4.29	0.26	11.67	1.30	103.16	0.00
S	Other Services	0.58	0.07	2.81	0.07	0.81	0.00

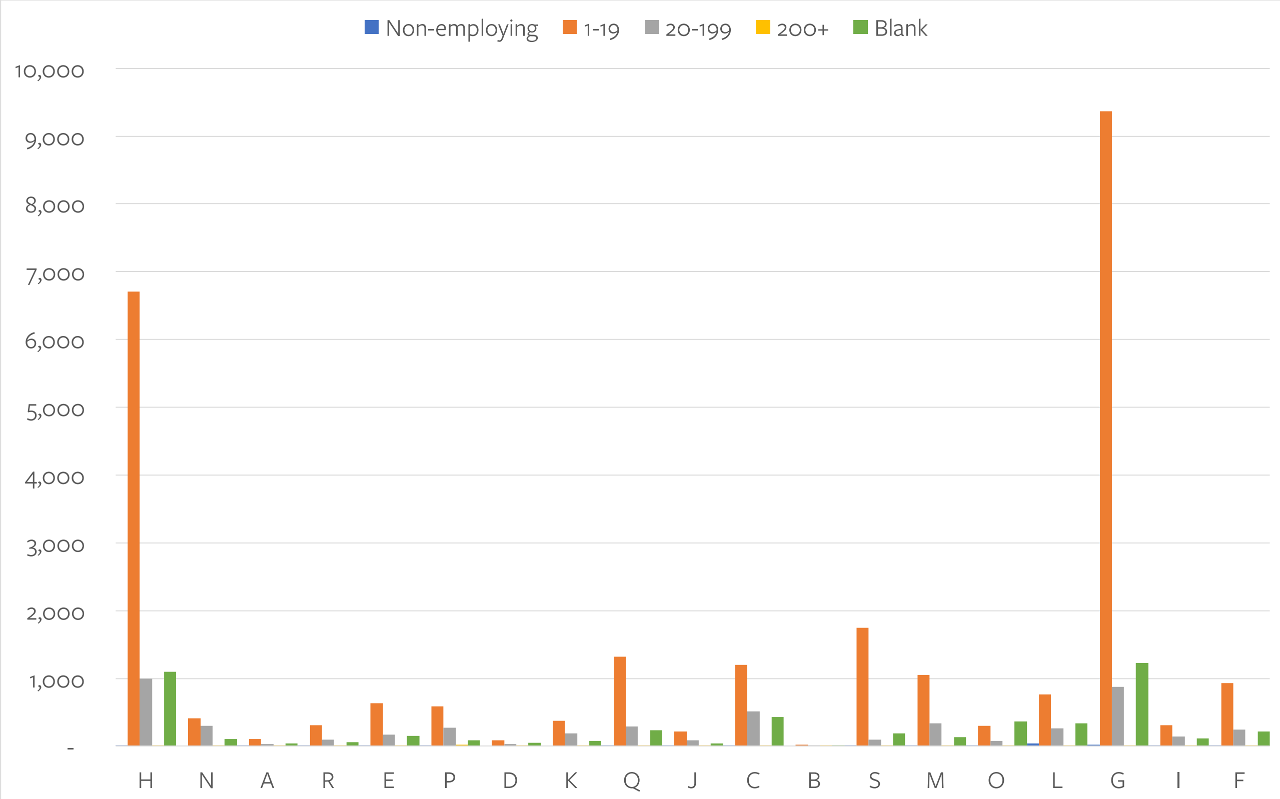
FO and GO waste arising from the non-residential sector are estimated by multiplying BinTrim factors (Table 12) with the number of businesses grouped by ANZSIC and by number of employees for each LGA (Table 9). However, non-employing businesses are not included in the calculation of non-residential FO and GO waste arising as it is assumed that waste generated through those businesses would be captured through the residential kerbside collection.

Non-residential FO and GO calculated using ABS factors and BinTrim data factors are compared to inform the framework to be used for the future estimation of non-residential UOW.

Uncertainty in factors determined from BinTrim data

Even though the BinTrim dataset includes a large number of datapoints, they are not uniformly distributed across all the categories (Figure 32). The majority of the datapoints sit within the *Retail trade* and *Accommodation and Food Services* categories. Businesses employing between 1-19 employees are most widely represented and there is a significant number of datapoints that did not include information about the number of employees (blank). Most of the ANZSIC groups include less than 10 data points for the businesses employing 200+ employees, giving this data a very high uncertainty and not statistically representative.

However, the majority of the businesses in the case study LGAs (Table 9) are either not employing or employ between 1-19 employees.



A	Agriculture, Forestry and Fishing	K	Financial and Insurance Services
B	Mining	L	Rental, Hiring and Real Estate Services
C	Manufacturing	M	Professional, Scientific and Technical Services
D	Electricity, Gas, Water and Waste Services	N	Administrative and Support Services
E	Construction	O	Public Administration and Safety
F	Wholesale Trade	P	Education and Training
G	Retail Trade	Q	Health Care and Social Assistance
H	Accommodation and Food Services	R	Arts and Recreation Services
I	Transport, Postal and Warehousing	S	Other Services
J	Information Media and Telecommunications		

Figure 32: BinTrim dataset used to derive factors for FO and GO estimation. Number of datapoints by ANZSIC groups by the employee, type of businesses, including data missing the number of employees (blank).

In addition, there is often a wide distribution in FO or GO values within the grouping category (ANZSIC group and number of employees), especially when only a smaller number of data points is available, resulting in poor representation of the group when applying an average value. For example, in the *Health Care and Social Assistance* group, the FO value distribution range increases as the number of points in the group decreases (Figure 33).

Histograms were developed for each group, and they assist in identifying extreme values, which are excluded in estimating FO and GO factors based on BinTrim data.

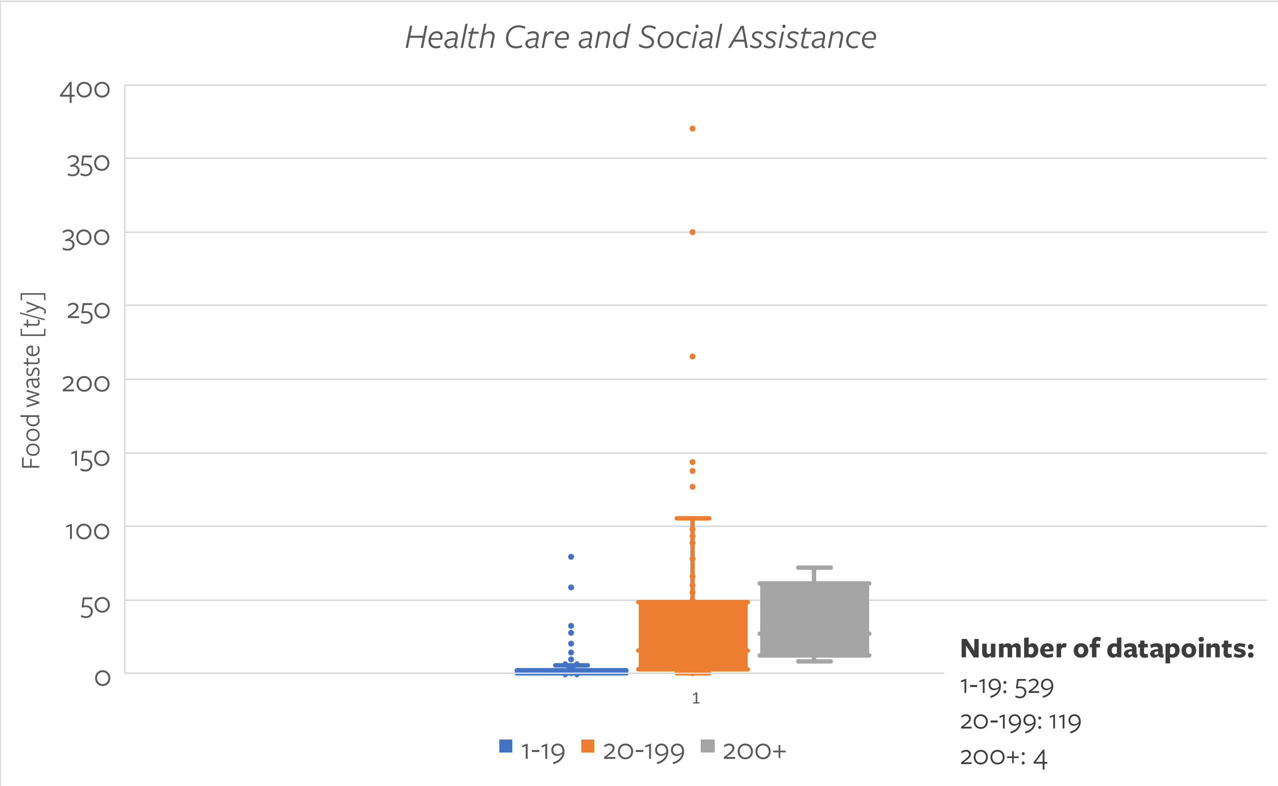


Figure 33: Statistical distribution of datapoints for the "*Health Care and Social Assistance*" group for FO [t/y] grouped by number of employees.

A.4.8 Calculation of fats, oils and greases generation

For fats, oils and grease (FOG) sourced from grease traps, data was provided by Sydney Water that included the estimated volumes of liquid and suspended solids collected at grease traps in the study area, and the geographical coordinates of each grease trap. This data is aggregated to the SA1 level by determining which SA1 each grease trap was located in (based on the coordinates provided in the data), and summed to calculate total FOG collections per SA1.

A.4.9 Calculation of liquid trade waste volumes

Data for trade waste was also provided by Sydney Water, including the estimated volume of liquid trade waste discharge to sewer, and total suspended solids content. Coordinates of businesses where liquid trade waste is generated was also provided, which is used to aggregate liquid trade waste discharge to the relevant SA1. While liquid trade waste discharge to sewer is mapped for this project, it is not considered in calculations for bioenergy potential, due to insufficient data on the composition of liquid trade waste, and uncertainty around data being actual measured discharge or volumes allowed under liquid trade waste agreements.

A.4.10 Calculation of the energy potential

Energy potential from digesting feedstock is estimated based on the assumptions and parameters from the academic literature. Methane and electricity generation is estimated for each feedstock, assuming mono-digestion. The purpose of this analysis is to characterise the maximum methane and electricity generation *potential* from each feedstock in the study area.

For residential and non-residential organic solid waste, the model in Lou et al. (2013) is used. In that paper, potential methane and electricity potential from the digestion of FO in a generic, mesophilic digester is estimated for the Australian municipal FO stream. This model is as follows (Equations 1 and 2):

$$CH_4^{org} = q^{org} \cdot f_{vs} \cdot b \cdot g^{org} \cdot c_{CH_4} \quad (1)$$

$$E_{AD}^{org} = \frac{1}{3600} \cdot CH_4^{ww} \cdot Q_{CH_4} \cdot \eta_e \quad (2)$$

Where CH_4^{org} is the potential volume of methane generation (in dam³) for organic solid waste, and E_{AD}^{org} is potential electricity generation (in MWh), for quantity of organic solid waste feedstock q^{org} (in tonnes/year). Further model variable descriptions and parameters used for this study are shown in Table 13. Parameter values are taken from Lou et al. (2013), as well as from (Hla and Roberts, 2015), which provided more detailed estimates of FO and GO volatile solids fractions.

Table 13: Parameter values used in the estimation of bioenergy potential from FO via anaerobic digestion.

Variable	Description	Value	Reference
f_{vs}	Ratio of volatile solids to total solids (food) [-]	0.54	Hla and Roberts (2015)
	Ratio of volatile solids to total solids (garden) [-]	0.42	Hla and Roberts (2015)
b	Volatile solids biodegradability [-]	0.83	Lou et al. (2013)
g^{org}	Biogas yield from organic waste [dam³ tonnes V/S destroyed]	0.55	Lou et al. (2013)
c_{CH_4}	Methane concentration in biogas [m³/m³]	0.71	Lou et al. (2013)
Q_{CH_4}	Heating value of methane [MJ /m³]	36.3	Lou et al. (2013)
η_e	Conversion efficiency [-]	0.34	Lou et al. (2013)

For residential and non-residential wastewater, methane potential is estimated assuming mono-digestion of influent wastewater, based on parameters in the academic literature. The following model is used (Equations 3 and 4):

$$CH_4^{ww} = q^{ww} \cdot \frac{TSS}{1000} \cdot ODM \cdot g^{ww} \quad (3)$$

$$E_{AD}^{ww} = \frac{1}{3600} \cdot CH_4^{ww} \cdot Q_{CH_4} \cdot \eta_e \quad (4)$$

Where CH_4^{ww} is potential volume of methane generated from wastewater (in m³), and E_{AD}^{ww} is the potential electricity generation (in MWh). Model variable descriptions and parameters are described in Table 14.

Table 14: Parameter values used in the estimation of bioenergy potential from wastewater.

Variable	Description	Value	Reference
TSS	Total suspended solids concentration [g/ kL]	260	Seiple et al. (2017)
ODM	Average organic dry matter in influent [-]	0.7	de Mes et al. (2003)
g^{ww}	Methane concentration in biogas [m³ /m³]	0.65	IEA Bioenergy (2015)
Q_{CH_4}	Heating value of methane [MJ/ m³]	36.3	Lou et al. (2013)
η_e	Conversion efficiency [-]	0.34	Lou et al. (2013)

For the FOG stream, methane potential is estimated based on the proportion of FOG added in a generic wastewater digester (2% FOG with sewage), from the model in Tandukar and Pavlostathis (2022). Although this approach assumes co-digestion of FOG with wastewater, only the methane generation potential from the FOG stream is calculated. The following model is used (Equations 5 and 6):

$$CH_4^{fog} = q^{fog} \cdot COD \cdot COD_d \cdot b^{cod} \cdot \gamma \quad (5)$$

$$E_{AD}^{fog} = \frac{1}{3600} \cdot CH_4^{fog} \cdot Q_{CH_4} \cdot \eta_e \quad (6)$$

Where CH_4^{fog} is potential volume of methane generated from methane (in m^3) for inputs of the liquid component of FOG (q^{fog} in L), and E_{AD}^{fog} is the potential electricity generation from the FOG stream (in MWh). Model variable descriptions and parameters are described in Table 15.

Table 15: Parameter values used in the estimation of bioenergy potential from fats, oils and greases (2%FOG with sewage)

Variable	Description	Value	Reference
COD	Chemical oxygen demand of FOG stream [g/ L]	0.355	Tandukar and Pavlostathis (2022)
COD_d	Rate of COD destruction [-]	0.921	Tandukar and Pavlostathis (2022)
b^{fog}	Methane yield per COD destroyed [L/g]	0.419	Tandukar and Pavlostathis (2022)
γ	Methane conversion, gas to liquid [m^3 gas/ m^3 liquid]	593	Tandukar and Pavlostathis (2022)

A.5. Results

A.5.1 Estimated bioenergy potential for residential and non-residential sources of feedstock, by LGA per year

Table 16: Estimated biomethane potential in m^3 per tonne of feedstock

Biomethane potential (m^3/t)	
Feedstock	**m^3 CH_4**
FO	176
GO	136
wastewater	0.081
FOG	90

Table 17: Estimated biomethane potential for residential UOWs by LGA per year.

Biomethane potential (residential sources)				
LGA	**FO [m^3]**	**GO [m^3]**	**Wastewater [m^3]**	**Total potential bio CH_4 [m^3]**
Blacktown	5,507,657	4,205,046	1,537,412	11,250,115
Penrith	2,560,063	4,627,077	851,380	8,038,520
Bayside	2,925,064	482,755	806,823	4,214,642
Randwick	1,147,270	1,227,540	599,324	2,974,134
Total	***12,140,054***	***10,542,418***	***3,794,939***	***26,477,411***

Table 18: Estimated biomethane potential for non-residential UOWs by LGA per year

Biomethane potential (non-residential sources)

LGA	FO [m³]	GO [m³]	Wastewater [m³]	FOG [m³]	Total potential bio CH_4 [m³]
Blacktown	2,262,701	1,395,590	341.986	90,628	4,090,905
Penrith	1,383,984	879,740	221,521	56,065	2,541,310
Bayside	1,955,001	1,166,027	256,515	68,500	3,446,043
Randwick	621,948	420,193	135,847	44,908	1,222,896
Total	***6,223,634***	***3,861,550***	***955,869***	***260,101***	***11,301,154***

Table 19: Estimated biomethane potential from combined residential and non-residential sectors by LGA per year.

Biomethane potential (all sources)

LGA	FO [m³]	GO [m³]	Wastewater [m³]	FOG [m³]	Total potential bio CH_4 [m³]
Blacktown	7,770,358	5,600,636	1,879,398	90,628	15,341,020
Penrith	3,944,047	5,506,817	1,072,901	56,065	10,579,830
Bayside	4,880,065	1,648,782	1,063,338	68,500	7,660,685
Randwick	1,769,218	1,647,733	735,171	44,908	4,197,030
Total	***18,363,688***	***14,403,968***	***4,750,808***	***260,101***	***37,778,565***

Table 20: Estimated bioenergy potential for residential UOWs by LGA per year.

Bioenergy potential (residential sources)

LGA	FO [MJ]	Garden waste [MJ]	Wastewater [MJ]	Total potential energy [MJ]	Total potential electricity generation [MWh]
Blacktown	199,927,938	152,643,174	55,808,051	408,379,162	38,569
Penrith	92,930,294	167,962,897	30,905,108	291,798,299	27,559
Bayside	106,179,830	17,524,002	29,287,693	152,991,525	14,449
Randwick	41,645,913	44,559,712	21,755,495	107,961,119	10,196
Total	***440,683,974***	***382,689,785***	***137,756,346***	***961,130,105***	***90,773***

Table 21: Estimated bioenergy potential for non-residential UOWs by LGA per year.

Bioenergy potential (non-residential sources)

LGA	FO [MJ]	Garden waste [MJ]	Wastewater [MJ]	Fats, oils and grease [MJ]	Total potential energy [MJ]	Total potential electricity generation [MWh]
Blacktown	82,136,033	50,659,937	12,414,109	3,289,799	148,499,878	14,025
Penrith	50,238,638	31,934,564	8,041,210	2,035,156	92,249,568	8,712
Bayside	70,966,537	42,326,769	9,311,483	2,486,550	125,091,339	11,814
Randwick	22,576,720	15,253,013	4,931,241	1,630,148	44,391,123	4,192
Total	***225,917,927***	***140,174,283***	***34,698,044***	***9,441,654***	***410,231,908***	***38,744***

Table 22: Estimated bioenergy potential from combined residential and non-residential sectors by LGA per year.

Bioenergy potential (all sources)						
LGA	**FO [MJ]**	**Garden waste [MJ]**	**Wastewater [MJ]**	**Fats, oils and grease [MJ]**	**Total potential energy [MJ]**	**Total potential electricity generation [MWh]**
Blacktown	282,063,970	203,303,110	68,222,160	3,289,799	556,879,040	52,594
Penrith	143,168,931	199,897,461	38,946,318	2,035,156	384,047,867	36,271
Bayside	177,146,367	59,850,771	38,599,176	2,486,550	278,082,864	26,263
Randwick	64,222,633	59,812,725	26,686,736	1,630,148	152,352,242	14,389
Total	***666,601,901***	***522,864,068***	***172,454,390***	***9,441,654***	***1,371,362,013***	***129,518***

A.6. Projections

Table 23: Dwelling projections by LGA for 2030/31

	Blacktown		Penrith		Bayside		Randwick	
	2020/21	**2030/31**	**2020/21**	**2030/31**	**2020/21**	**2030/31**	**2020/21**	**2030/31**
Number of SUDs	98,390	117,587	57,406	67,993	22,366	22,366	13,797	13,797
Number of MUDs	22,361	26,724	15,490	18,347	41,734	50,247	37,050	50,401
Total dwellings	120,751	144,311	72,896	86,340	64,100	72,613	50,847	64,198

Table 24: Organic waste generation projections by LGA for 2030/31

	Blacktown		Penrith		Bayside		Randwick	
	2020/21	**2030/31**	**2020/21**	**2030/31**	**2020/21**	**2030/31**	**2020/21**	**2030/31**
FO [t]	31,298	37,309	14,511	17,187	16,580	18,362	6,503	7,965
GO [t]	30,987	37,032	34,096	40,384	3,557	3,830	9,046	10,522
Wastewater [GL]	25.9	30.9	14.3	17.0	13.7	15.3	10.2	12.0

Table 25: Projected bioenergy generation potential (in MWh) by LGA for 2030/31

	Blacktown		Penrith		Bayside		Randwick	
	2020/21	2030/31	2020/21	2030/31	2020/21	2030/31	2020/21	2030/31
Bioenergy potential [MWh]	38,569	48,342	27,559	33,876	14,449	17,109	10,196	13,036

A.7. IRG Inception meeting synthesis

A.7.1 Introduction

This document provides a brief synthesis of the materials presented in the Inception Meeting for the RACE for 2030 project "Mapping Organic Waste in Sydney", held on 16th December 2021, as well as feedback by the project Industry Reference Group.

A.7.2 About RACE for 2030

Overview

RACE aims to accelerate the transition to Reliable, Affordable, Clean Energy by 2030 through innovation focused on energy end users and the networks that supply them. It is a collaborative industry led Cooperative Research Centre (CRC) established in 2020 with $68.5M of Commonwealth funding. Other resources coming from partners who cover the whole value chain from end user back to network, technology companies, governments, and many of Australia's leading energy researchers. The RACE for 2030 ten-year program has the largest committed resources of any CRC created to date.

Programs

The research is organised into four programs:

- RACE for Business,
- RACE for Homes,
- RACE for Networks and
- RACE for Everyone (covering cross-sectoral issues).

This project is part of the RACE for Business program: Boosting business energy productivity and cutting costs via digitalisation, electrification, and value chain optimisation. And is under Theme B5: Anaerobic digestion for electricity, transport and gas.

A.7.3 Industry Reference Group (IRG)

The purpose of an IRG, an independent advisory group, is to ensure that the views and priorities of industry, end use customers and other key stakeholders are considered in the planning and conduct of each project. This will help to ensure that research addresses real industry problems and maximises positive impact for customers. Commitment is to attend three two-hour meetings plus allow 4-6 hours for reviewing documents over the 6-month project period across different project phases:

- **Project inception** – to set up project expectations and to ensure that the project addresses industry issues.
- **Project mid-point** – to discuss findings and assess if project needs adjustment to address industry needs.
- **Project conclusion** – to share outcomes with stakeholders, test that stakeholders' expectations are met and to evaluate the project.

A.7.4 About this project

3.76 Mt (85%) of food waste was landfilled in Australia in 2018/19 of which 71% was collected through the Municipal Solid Waste (MSW) and 29% through Commercial and Industrial stream (C&I). Landfilled food waste poses an environmental stress through greenhouse gas emissions generated during the decomposition process and loss of nutrients. Currently Sydney has only one commercial AD plant with the capacity of 1000t/w and often has operating and reliability issues. On the other hand, Sydney Water has 14 AD plants for sludge management with spare capacity that could potentially be used for co-digestion. This project aims to bring together siloed waste, wastewater and energy sectors to help meet cross-sectoral policy obligations.

The focus in this 6-month RACE project will be on three Sydney Water WWTPs (see Figure 1) and to gather geospatial data on food waste and broader urban organic waste to assess the bioenergy potential. Urban organic waste (UOW) occurs across residential, commercial and industrial, and institutional sectors. In addition to food waste and garden waste urban organic waste includes pet waste, used cooking oil, fats oils and greases, sewage waste and trade waste.

There is a potential to expand the analysis in a longer-term RACE project (e.g., broader area – Sydney and deeper analysis – cost and benefits).

Figure 34: WWTPs in focus for this RACE project.

Research team

The core research team includes:

- Andrea Turner (Project Lead)
- Dr Melita Jazbec (Project Manager/ Analyst)
- Ben Madden (Analyst)
- Prof. Long D. Nghiem (AD specialist)

Project Objectives

- Use organic resources for higher order CE benefits by redirecting unavoidable UOW to AD to reduce landfill impacts, lower GHG emissions, generate bioenergy and recover nutrients.
- Use existing AD infrastructure (e.g., Sydney Water WWTPs with capacity) for co-digestion to optimise existing assets and defer capital infrastructure costs
- Bring together waste, water and energy sectors to harness these opportunities and fill knowledge gaps such as quantifying the various UOW streams available, their energy potential and geospatial proximity to Sydney Water AD assets
- Develop an analytical and mapping framework that can be used more broadly across Sydney and potentially NSW and other jurisdictions to showcase the value of AD not yet harnessed in Australia.

Examples of some of the potential project impacts

	SHORT TERM	**LONG TERM**
	130 kt/y of food waste diversion from landfill and $20 mil/a saving in landfill levy (with gate fee net saving $6 mil/a)	235 kt/y of food waste diversion from landfill and $12 mil/y net saving in landfill levy including gate fee
	Increase in energy generation by 27% due to co-digestion	Increase in energy generation by 27% due to co-digestion
	Generation of 21 GWh/y of electricity – powering 3,000 households	Generation of 37 GWh/y of electricity – powering 5,000 households
	$5 mil/y savings in electricity bills	$8 mil/y savings in electricity bills
	$19 mil saving in avoided infrastructure investment	
		444 kt/y CO_2-e reduction in emission

IRG Group objectives and expectations

The objectives and expectations of the project were discussed during the workshop and are summarised in italic under various themes below. These will be incorporated into the scope where feasible and if outside possible scope (e.g., costing) they will be identified for possible inclusion in the proposed subsequent project.

- **Mapping of the stakeholder value chain**
  Map the players and stakeholders in the value stream and what their role is in unlocking feedstock.
- **Braking cross sectoral barriers**
  Understanding the alignment and role between the Council, Sydney Water, DPIE and Power users in planning. Ensuring that the different values in sectors are considered.
- **UOW processing options**
  Understanding current waste streams/markets in Sydney and what are the processing options, their value (including energy and storage) and gate fees.
  Understanding the geographical distribution of UOW, streams fluctuations, what are safe and cost-effective collection and processing opportunities and gains, what are the barriers. Establish the organic waste diversion from landfill, impact on council efforts on food waste reduction strategies, value of waste streams through operational risk and benefits, and understand the impact and what is a viable waste transport distance.
- **Processing UOW with AD**
  To build an understanding and trust in AD processing, and to identify pathways for impactful outcomes. Identify the barriers, such as existing contracts and assets, policy, approval pathways, commercial and technological limitations.
  Identify the optimal use (from cost and benefits perspective) of dedicated infrastructure for co-digestion (existing or new), sites based on demand and organic waste type, need for supporting infrastructure – transfer stations and treatment (de-contamination, maceration, etc).
  Information to assist the partners with planning and investments.
- **Solution for commercial UOW**
  A commercial offering for the business to take their waste there.
- **Establishment of research framework for knowledge sharing**
  Develop a framework for broader waste mapping, data sharing and conversion factors of different food wastes to gas/energy (e.g., kg to kWh)

Examples of research outputs

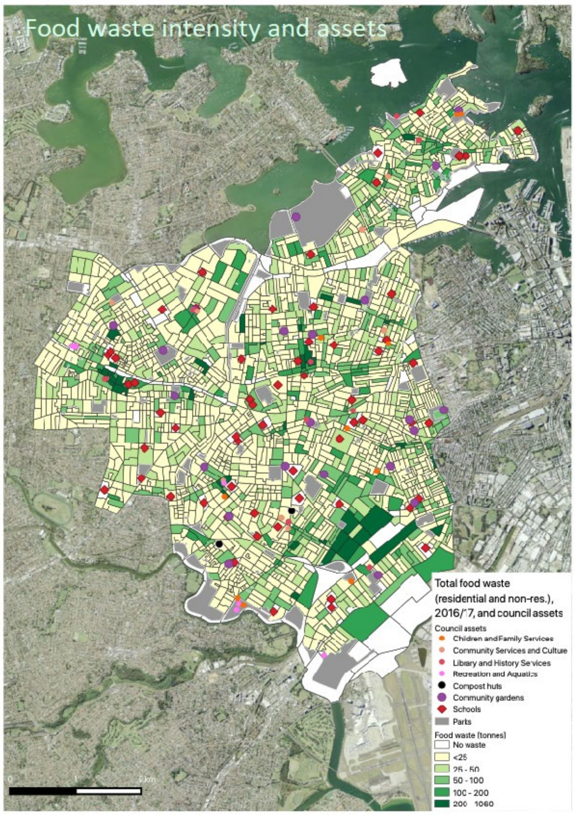


Figure 35: Total food waste (residential and non-residential) for 2016/17 in Inner West Council and council assets.

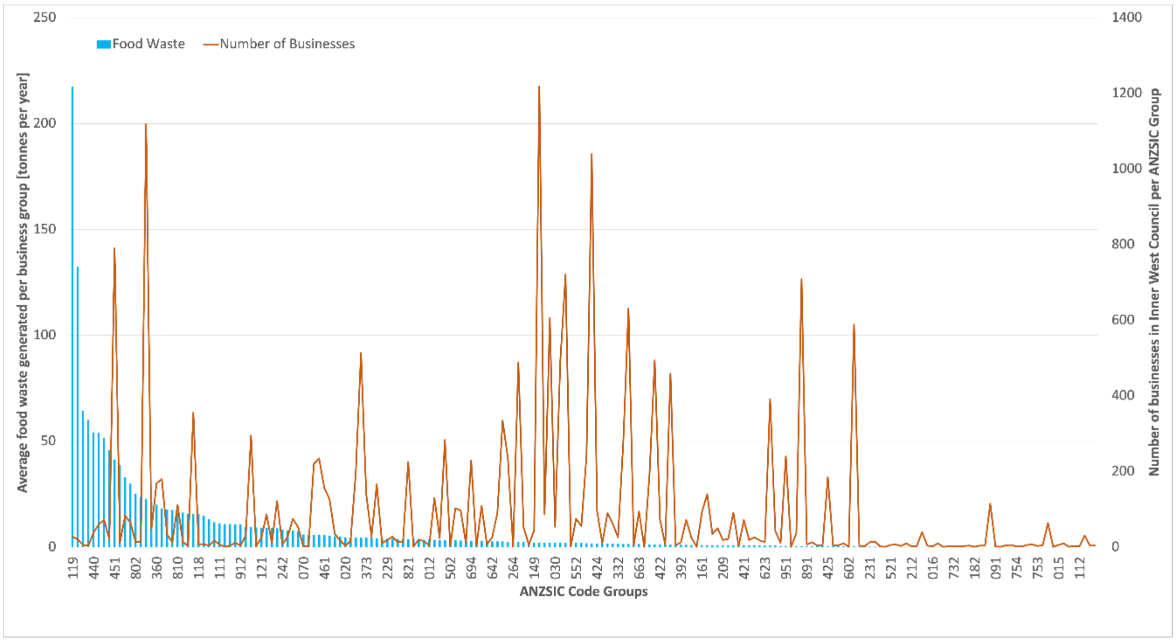


Figure 36: Estimated average food organics generated per business group (ANZSIC) in t/y and the number of businesses in IWC per ANZSIC group.

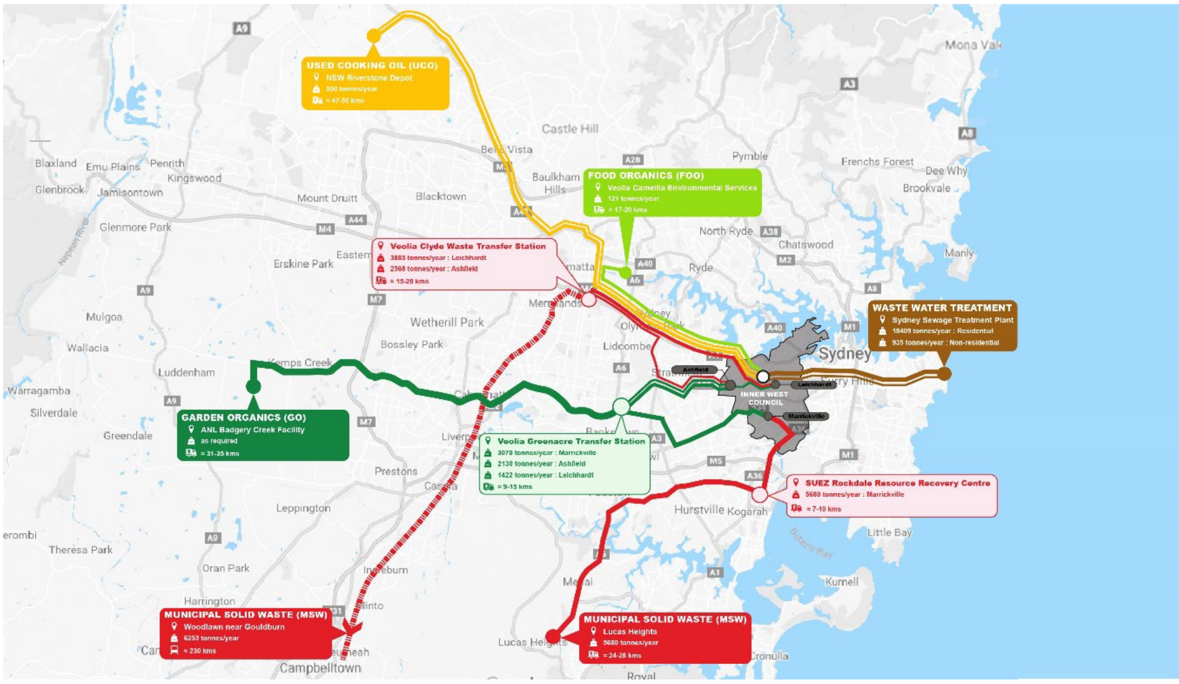


Figure 37: Organic waste streams destination for the Inner West City Council.

Project plan

During the workshop feedback was sought on the proposed project plan and outputs. The figure below summarises the feedback gathered, which will be incorporated into the scope where feasible.

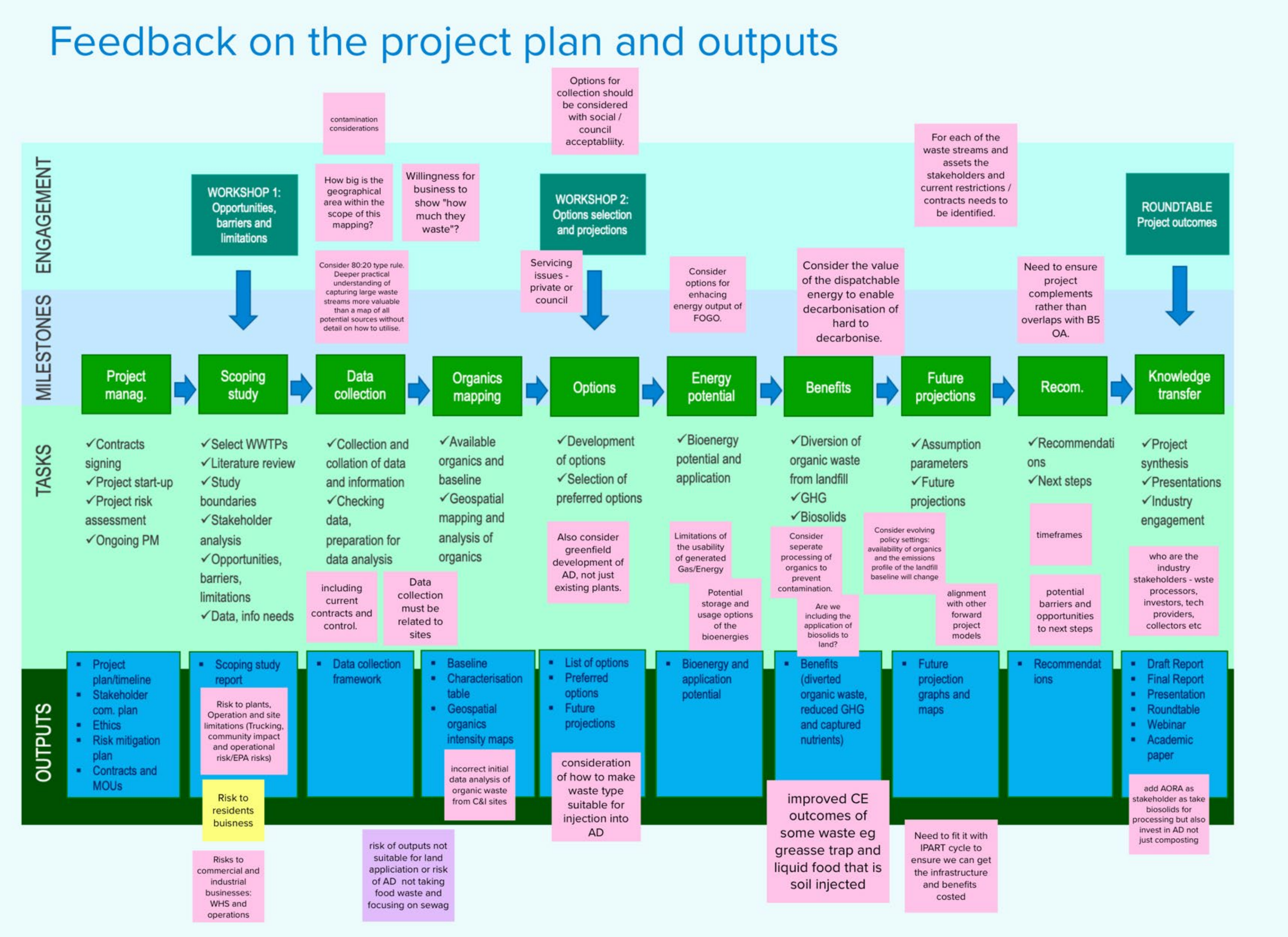


Figure 38: Feedback from workshop participants on the Project plan provided on stickies.

Partners contributions and benefits

Table 26: List of contributions and benefits for the project partners.

PARTNERS	CONTRIBUTIONS	BENEFITS
Sydney Water	• Data on sewage, FOG, AD, WWTPs, Energy Generation Potential • Financial support	• Estimates of potential UOW streams and energy generation • Sub-sector/contracts for redirecting appropriate organics for selected WWTPs.
DPIE, NSW EPA	• Access to existing studies and data on non-residential and residential waste sectors • BinTrim data for analysis • Financial support	• Help fill knowledge gaps on estimates of non-residential UOW in Sydney • Identify potential sub-sectors for achieving higher order CE benefits for waste industry • Outputs used to determine alternative pathways and associated investment for UOW streams currently passing to landfill.
Blacktown CC, Bayside C, Penrith CC, Randwick CC	• Waste generation data • Waste audits data • Business types in the LGA	• Provide information for the local councils in the vicinity of WWTPs to assess opportunities for local and centralised UOW management solutions to help achieve strategic objectives and government targets • Ability to see where organics are generated within the LGAs to work with contractors and communities redirecting organics to AD.
Sustainable Advantage	• Non-residential waste and business data	• Knowledge gap on UOW from non-residential sector
DPI	• Data from NSW ABBA project	• More information for the NSW ABBA project
Jemena	• Biogas application options and data • Requirements for application of biogas in the network grid	• Estimated generation of biogas from the AD using co-digestion.

Data information and requirements

Figure 39 below shows the components of UOW generation/inputs and options considered in the project that will require data and information inputs for the delivery of the project outputs.

Data types, data sources and information requirements were discussed during the workshop and are summarised in italics below. The workshop participants' input will be considered when possible and if within the project scope, alternatively the suggestions will be considered for the proposed subsequent project.

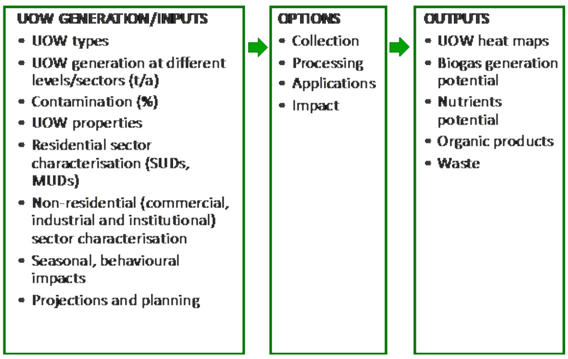


Figure 39: Project component requirements.

- Data types
    - *Gas to grid rather than onsite power generation*
    - *Types of potential lower emissions building products*

- *Foresight and expectation of growth in the LGA - both residential and business*
- *EPA GHG profile of food management pathways*
- *Infrastructure costs*
- *Impact of increase of compostable packaging*
- *Capacity of planned new AD in initial years of operations*
- *Data on organisations that are reporting zero waste to landfill and organics that are already being processed*
- *Dispatchable energy provided through biogas*

- Data sources
  - *Blacktown City Council doesn't service commercial and industrial - might be difficult to acquire this information*
  - *Collaboration of Jemena in Malabar – generation of green gas*
- Additional information
  - *Existing contractual agreement types and conditions (e.g., Council agreements can be 10-15 years)*
  - *New contractual agreements based on commitments and limitations (e.g., inability to take food waste – plan B option or penalties for lower volumes than contracted)*
  - *Alternatives to operational breakdown due to organisations zero waste commitments*
  - *Fluctuation based on plant operations*
  - *Waste products and returns impacts*
  - *High value waste vs Low value waste (sewage being contaminated with Hormones, PFAS, Heavy metals etc.)*
  - *Restrictions in mixing organics with sewage*
- Notes
  - *Greenfield AD, is it in scope?*
  - *Best option for the location*
  - *Malabar breakdown could not be compensated by other ADs*
  - *Composting vs AD*

Project risks and mitigation

Development of a project risk and mitigation plan is currently underway. We have identified the following anticipated risks:

- *Limited access to appropriate data for analysis due to partner privacy or commercial in confidence*
- *Timing constraints with data delivery*
- *Data quality impacting quality of analysis*

For the identified risks we have identified the following risk mitigation approach:

- *Development of mitigation plan for the identified risks*
- *Hold and review points for the projects*
- *Agree on essential data and analysis vs optional data and analysis*
- *Rescoping research tasks if necessary and as agreed*

Next Steps

- Data collection

  We will start with the data collection and establishment of MOUs for data sharing as required.
- Literature review

  We will start with a high-level literature review (academic and grey literature) on current policy situation affecting the cross-sectoral waste, wastewater, energy industries, on the latest advancements, opportunities and barriers on co-digestion of UOW with wastewater (e.g., contamination), key technologies for WWTP co-digestion including UOW collection, pre-treatment, and UOW treatment, other options for UOW management, biogas potential and measures to enhance the biogas generation and supply reliability, co-digestion digestate potential and barriers, current strategies and planning of the LGAs in focus and scan of past relevant studies on UOW and associated data opportunities. While much of these has been already conducted under previous studies, this will be an opportunity to collate this information, update where appropriate and provide broad contextual background to the project.

- Boundary criteria matrix
  A criteria matrix (that can be applied for all LGAs and used for the proposed future CRC ST project) will be developed to assist in determining the study boundary. The criteria will include for example geographical distance from the WWTPs, data availability and quality requirements and existing waste management arrangements. We will identify the streams (e.g., FO, GO, FOG, UCO) and sectors (residential, non-residential) as well as key sub-sectors present in the focus LGAs based on available data and determine the boundary of the study using the criteria matrix.
- Key stakeholder network
  In addition to the IRG, we will identify key stakeholders along the UOW supply chain in the LGA focus area and conduct preliminary stakeholder mapping from various perspectives (e.g. control-influence-concern, generation-management-end use, federal/state/local government-private industry-community stakeholders) model.
- Upcoming workshops
  The following workshops are planned. Exact dates will be determined closer to the time according to IRG members availability.
  Workshop 1 *– Identify opportunities, barriers, and limitations – end February/beginning of March*
  Workshop 2 *– Selection of preferred options for the analysis – April*

A.8. Workshop identifying opportunities, barriers, limitations and options for processing UOW to generate energy and reduce GHG emissions

A workshop was held with the project partners and IRG to identify the most feasible and preferred options for the generation of bioenergy from co-digestion on 20 October 2022. This section synthesises outcomes of the workshop.

A.8.1 List of options, barriers and opportunities

Potential options have been grouped by feedstock, digestion process and bioenergy application.

A traffic light system is used to indicate agreed suitability of the options for co-digestion investigation by workshop participants:

- **Green**: feasible with adequate data available
- **Orange**: further study required or data hard to obtain
- **Red**: out of scope due to not being suitable to AD or data extremely hard to obtain.

FEEDSTOCK OPTIONS		
FOG Non-residential FO Retail and food service FO	Residential FO Institutional FO	UCO Trade wastes

UCO are not considered a suitable feedstock for an AD, particularly due to the more suitable processing option of conversion to biofuels. Even though some of the trade wastes are suitable for AD, they are also considered out of scope for this study due to their heterogenous properties which make it difficult to investigate and characterise especially as part of this relatively short study.

Institutional FO is an organic waste stream typically sent to landfill and therefore offers great landfill diversion opportunities through organic waste processing (Figure 1). While this project did not focus on this stream, it should be considered in future studies. Residential FO provides significant opportunities due to available volumes of feedstock. It has however been perceived by workshop participants likely to be a contaminated stream with variable composition. In addition, the participants identified that current strategic direction of collecting FO in FOGO bins would further complicate the potential for co-digestion at WWTPs.

The FOG stream from the non-residential sector was considered the most attractive feedstock for the co-digestion at WWTPs due to its high biogas generation potential.

DIGESTION OPTIONS		
Maceration	Joint operation with waste facilities	Post AD (gasification and pyrolysis) to deal with contamination
De-contamination Stand-alone AD for residential FO (co-location) Co-digestion	Liquid AD	Other conversion technologies to convert green waste to energy

There are several options for renewable energy generation from UOW, in addition to AD. However, use of alternative technologies to convert GO to energy is considered out of scope for this study. So is post AD conversion to energy (e.g., gasification and pyrolysis), an approach suggested by workshop participants to deal with contamination of feedstock.

Options including joint operation with waste facilities and liquid AD, were recommended to be considered in the next stage of the study.

In the digestion analysis, preparation of the feedstock for AD, such as maceration and de-contamination, were recommended by workshop participants to be considered. While the main focus of this study is co-digestion (where multiple organic feedstocks are combined and digested in an AD), co-location (where multiple feedstocks are digested or processed at the same location but in separate digestors) was also recommended by the workshop participants to be considered. However, one of the main advantages of co-digestion is the enhanced generation of bioenergy and an opportunity to use existing infrastructure and location. The workshop participants though, have pointed out that there are limitations in terms of feedstocks, potentially introduced contamination due to combining multiple streams, challenges in operation due to reliability of feedstock supply and pre-processing requirements, as well as challenges from management of multiple stakeholders.

BIOENERGY OPTIONS		
Electricity Thermal energy in industry (e.g., current natural gas users) Cogeneration and trigeneration of electricity, heating, and cooling	Replacement to natural gas	Transport fuel (BioCNG, BioLPG) Dimethyl ether (DME)

Biogas produced in AD is a mix of CH_4 and CO_2 with concentrations of CH_4 between 50-75%. Depending on the application, the biogas is required to undergo different levels of treatment and therefore requires additional infrastructure. Application of biogas for use in transport requires the highest biogas purity and is considered out of scope for this project.

Application of biogas as a replacement for natural gas in the gas network, requires biogas to be concentrated to 96% by removing CO_2 and impurities, such as H_2S and water. This application is not considered in the analysis in this study but was recommended by the workshop participants to be considered in future studies.

The recommended options by workshop participants were: co- and trigeneration (for heating and cooling), thermal energy for adjacent industry, and energy generation for further analysis as part of this study.

A.8.2 Opportunities and barriers of UOW feedstock, digestion and bioenergy options

Opportunities and barriers of UOW feedstock, digestion and bioenergy options, as identified by workshop participants, are summarised in Table 27.

Table 27: Opportunities and barriers for UOW feedstock, digestion and bioenergy options for the AD in WWTPs (as identified by workshop participants).

	Opportunities	Barriers
Feedstock options	• NSW policies for organic waste: separate collection of FO from targeted businesses by 2025 in NSW and separate FOGO collection by 2030 for residential sector • Adoption of circular economy principles for organic wastes and highest value options for organic resource recovery via AD • Combine with other feedstock (e.g., agricultural residues) • Diversion of current high volume of organic waste deposited to landfill • Education about organic waste processing opportunity to generate energy (businesses and consumers)	• Cheaper existing options for the UOW feedstock (e.g., direct soil injection of FOG) • Competition for FO (e.g., food for animals) • Regulations (e.g., biosolids application regulations) • Complexity due to mixed feedstock • Contamination of the feedstock (e.g., bioplastics, films) and additional infrastructure cost for decontamination • Changes to the current waste management system, availability of infrastructure, required volumes, frequency of collection • Industry contracts (lengths, need for new) • Closeness to AD • Feedstock variability and seasonal issues
Digestion options	• Strategic directions: striking balance in achieving net zero strategies goals, reliability of the system at a low cost • Organic waste governance: opportunity to adopt the Copenhagen system where the digestor operators own the bins and trucks • Use of certification process • Communication between sectors • Organic waste diverted from landfills and flaring • Opportunities of digestate applications (fertilisers, vertical farms in urban areas) • Operation optimisation (e.g., heat only as required, repurposing existing assets, co-location of ADs, combined AD and composting for FOGO stream (AD for the liquid and composting for the solids), close to users of digestate) • Utilisation of waste gases for other purposes • Addressing feedstock contamination with post-digestion treatment (e.g., use of pyrolysis/gasification to eliminate contaminants from biosolids) • Alternative processing technologies (e.g., cellulose hydrolysis, hydrothermal liquefication)	• FOGO – mixed GO and FO stream • Not source separated • Existing and aging infrastructure • Contamination of the feedstock • Contaminated outputs • Over production
Bioenergy options	• Replacement of natural gas to sectors that cannot de-gasify • Upgrade gas for grid injection • Use on site • Behind the meter/local energy supply options • Certifications and credits (credit for avoided emissions) • Organic resource and energy governance • Shared risks between government, customers and businesses	• Financial viability in the energy market – energy prices and landfill levy • Cost of bioenergy vs alternative renewable energy sources (business model, payback, customers willingness to pay) • LGCs for renewable gas and decarbonisation policy • No feed in tariffs for biogas • No incentives to upgrade biogas to the grid quality (behind the meter better option) • Use of CO_2 • No biogas accreditation/certification scheme and no clear standards

A.8.3 Relevant stakeholders for the selected options

Table 28 identifies potential stakeholders for the selected feedstock, digestion and biogas options as identified by the workshop participants.

Table 28: Potential stakeholders for the feedstock, digestion and biogas options as identified by workshop participants.

FEEDSTOCK OPTIONS:	DIGESTION OPTIONS	BIOGAS OPTIONS
• Waste aggregators • EPA • NSW Health • FO processing technology suppliers • Waste processing facilities • Local government	• EPA (operation team regarding licencing) • EPA (resources recovery team, regarding orders exemptions)	• Consumers • CER • Gas network regulators and operators • OECC/GreenPower scheme • Companies with SBTI or Scope 1 reduction targets • Industrial, commercial, institutional gas users • Building rating scheme

A.9. Project risks mitigation plan

Table 29: Project risk mitigation plan

Potential risks	Mitigation	Risk level
Non-RACE financial partners • Delay in contractual agreements with non-RACE partners could potentially delay the timeline of partner's contributions (e.g., NSW EPA)	• Bring the non-partner into RACE as a tiered partner • RACE develop a non-partner short-contract/letter of agreement to streamline the process for the specific project and all future RACE projects	High
Stakeholders dropping out • Stakeholders may no longer want to be involved with the project (e.g., Councils involved in our project)	• Modification of methodology, e.g., develop an additional simplified methodology to assist in the potential RACE standard project associated with this project and the potential difficulty of garnering support from all Sydney councils in future • RACE develop a letter/email pro-forma for all potential partners to agree to participation and/or financial contribution to tighten agreement process for future projects as is commonly used in collaborative research projects	Moderate
Data availability • Assumed datasets are not available or in public domain	• Methodology based on proven datasets from past projects • Identify a process to access the data not in public domain • Use alternative data sources • Modify methodology to use the alternative available data set/s	Low
Accessing data • Not being able to access data due to privacy or data governance arrangements • Delays in datasets delivery	• Modify methodology to address issues with privacy, such as change the granularity of geospatial analysis and mapping • Stage data acquisition and analysis from various sources to test on smaller available datasets first	Moderate
Data quality • Incomplete datasets, errors, variability	• Data cleansing, application of statistical analysis and use of additional datasets for sense check	Moderate
Covid • Team members, partners or stakeholders becoming ill or in self isolation due to covid	• Utilise online tools for meetings and workshop • Allow for flexibility in the timeline	High

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