Supplement A: Social acceptance of biogas in Australia - a descriptive and thematic literature review

February 2023

Project number: RP 2.1-02

A social license and acceptance of Future Fuels

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Project Information	
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Research Program	RP2
Milestone Report Number	8 (Report on national survey on public perceptions of biogas)
Description	This supplement provides the findings of a literature review on social acceptance of biogas and biomethane to support the detailed report on the national biogas survey
Research Provider	University of Queensland
Project Leader and Team	Professor Peta Ashworth Dr Amrita Kambo Dr. Alain de Sales Mr. Abel Quintero Fuentes
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Summary of Report

This report provides a literature review on the social acceptance of biogas in Australia conducted in 2021 to inform the development of a national biogas survey conducted in 2022. The broad aim of the literature review was to identify what role biogas/biomethane projects may play in Australia's low-carbon future fuel mix. Firstly, an introductory review was conducted to narrow down on specific objectives within the broad aim of understanding the social acceptance of biogas in Australia. Secondly, a critical interpretive review was conducted to meet the specific objectives identified as follows:

i) identify challenges, opportunities, trade-offs and priority actions that have emerged from the experience of other nations;
ii) show how these experiences may inform Australia's transition to a low-carbon energy future in relying on biogas/biomethane as an option within the future energy mix.

The results show that the biogas/biomethane industry in Australia is at a very early stage in its development. Biogas offers an opportunity to use locally produced waste as an input to generate fuel and digestate as outputs. In this way, biogas offers value in closing the loop on waste, producing energy and fertiliser, and so represents the circular economy concept (Enea Consulting, 2019). Biogas plants act as hubs in the circular economy, where streams of excess materials, previously regarded as waste, from industrial processes, agriculture and other human activity are channelled through anaerobic digesters and converted to useful energy carriers, nutrient-rich organic fertilizer and novel materials (Fagerstrom et al., 2018). Anaerobic digestors are closed, airtight, fermenter tanks that facilite the upcycling of waste into energy (Fagerstrom et al., 2018). Biogas obtained from anaerobic digestors can be upgraded into 'biomethane' which has a chemical composition very similar to natural gas. Biomethane can be injected into gas grids or used as fuel in transport vehicles (Enea Consulting, 2019; Fagerstrom et al., 2018).

In Australia, biogas production is estimated at 1,587 (GWh/year) based on installed capacity of 242 anaerobic digestion (AD) plants (IEA Bioenergy, 2019). Almost half of these facilities are based at landfills which collect landfill gas. A significant amount of biogas sourced at landfill is not used as fuel but flared at source. There is an opportunity for Australia's biogas industry to curb biogas loss through flaring if infrastructure is developed to convert landfill gas into electricity (Enea Consulting, 2019). Secondly, there is an opportunity to develop upgradation facilities to process poor quality biogas into biomethane, offering an alternative low-carbon fuel for municipal grids and/or transport (Enea Consulting, 2019).

However, the review has shown that infrastructure development for biogas/biomethane has a clear dependency on social acceptance. As with other technologies, acceptance or resistance has been known to make or break biogas/biomethane plants internationally. Acceptance in turn has an interdependency with policy frameworks, communication and engagement strategies. And so, successful biogas/biomethane infrastructure development must take a considered approach in resolving any vulnerabilities that arise from the nexus between social acceptance, policy and engagement.

In the Australian case, literature on the status of social acceptance towards biogas/biomethane is scarce. However, there is an abundance of social acceptance literature in relation to other renewable energy (RE) technologies. Such literature can help to inform future research aimed at understanding the Australian psyche towards biogas/biomethane.

With this view, the review undertaken thus far, has justified the case for a detailed scoping study as the next step. There are prospects to shape future research based on the findings detailed in Chapter 4. The conceptual framework (Figure 10) of social acceptance of biogas/biomethane in Australia can be enhanced. There is scope to further refine and expand this conceptual framework based on nuances of:

- scale – whether national, regional, local, rural, or urban;
- context – where, when, how, and for whom;
- findings reported in past studies on Australians' social acceptance of other RE technologies.

In the first instance the research might include interviews with key stakeholders from the existing industry and focus groups and a national survey of the general public to better understand current responses to the concept of biogas/biomethane. The findings arising from such research will help to contribute in real terms to policies and engagement strategies around Australia's low-carbon future fuel mix.

1 Introduction

Increasingly, businesses in economically advanced democracies recognise the importance of operating within the boundaries of their 'social licence' (Gunningham et al., 2004). Opposition and social disapproval are challenging barriers to overcome. Therefore, corporations are actively choosing to go beyond mere compliance and pursuing social acceptance as a goal. As with other industries, the renewable energy (RE) sector, must actively seek social acceptance in a bid to overcome community resistance (Wüstenhagen et al., 2007) . A social licence has been identified as a critical first step in ensuring the success for nascent RE projects, as the global environmental benefits of RE alone, are not always convincing enough for some stakeholders (Segreto et al., 2020), especially in the Australian context (Hall et al., 2013; Martin & Rice, 2015).

We are also aware that the growth and community-wide adoption of RE is intrinsically linked to policy. Renewable energy policies, in turn are influenced by public opinion. For example, rapid adoption of biogas deployment in Germany occurred since the implementation of the Renewable Energy Act (REA) in 2000, but diminished after policy changes decreased the support subsidy schemes for biogas (Horschig et al., 2020). In contrast, in the United States of America, biogas plays a significant role in the transport sector due to the support of federal and state policies (IEA, 2020b; Schmid et al., 2019). Similarly, in the EU, support schemes promoting the utilization of renewable resources have encouraged the development of biogas plants for energy production.

Clearly, biogas technology offers a very attractive route to utilize biomass for meeting partial energy needs (Balat & Balat, 2009). However, as with other sources of RE, the success of biogas powerplants is also dependant on social acceptance. For example, in Germany and Italy, negative public opinion towards the cultivation of maize for energy crops, resulted in restraints that negatively impacted the development of biogas projects (Cicia et al., 2012; Horschig et al., 2020). Generally, investors are reticent towards biogas as an alternative source of RE in comparison to solar and wind energy which capture the lion's share of new financial sector investments worldwide (International Energy Agency, 2021). A US based survey has shown that investors' willingness to invest in biomass based energies all had very low mean values in comparison to the top choices (solar and wind) due to perceptions around uncertain and long return cycles (Aguilar & Cai, 2010).

These experiences highlight the necessity of exploring social orientation towards biogas and energy crops in the Australian context. It is known that the investment opportunity for new bioenergy and energy from waste projects is estimated to be between $A3.5 to 5.0 billion, with the potential to avoid up to 9 million tonnes of CO_2e emissions each year (Enea Consulting, 2019). It is also known that unfavourable policy, currently stands as a barrier towards fulfilling this potential (Enea Consulting, 2019). Recognising that social acceptance can shift policy perspectives, community awareness around biogas may play a crucial role (Enea Consulting, 2019). A study on public attitudes towards biogas and biomethane is warranted given the lack of literature surrounding this issue in Australia (Table 1, Table 2, Table 3, Table 4, Figure 2, Figure 3).

To this end, with an initial introductory review around the social acceptance of biogas in Australia is conducted. The broad aim is to establish the extent of existing knowledge, identify prominent ideas shaping contemporary debate, knowledge gaps and identify what might form the basis for future research. Based on the findings of the introductory review, the scope of the review was narrowed around specific objectives – namely:

i) identify challenges, opportunities, trade-offs and priority actions that have emerged in the biogas space from the experience of other nations;
ii) show how these experiences may inform Australia's transition to a low-carbon energy future in relying on biogas/biomethane as an option within the future energy mix.

To fulfil the broad aim and meet the specific objectives of the review, the report starts with technical information detailing what is biogas/biomethane as well as providing a comparison of the international and national biogas production scenarios (Chapter 2). Next, the review method and processes are explained (Chapter 3). Chapter 4 summarises the main findings that arose from the review - issues relating to social acceptance and perceptions; and identifies potential drivers, barriers and stakeholders; their roles and interdependencies within specific socio-techno-political variables. Chapter 5 documents the conclusions and key recommendations that follow from the findings.

2 Research Methods

A thorough literature review on the social acceptance of biogas and biogas in Australia is a vital first step in discerning what role biogas/biomethane projects may play in Australia's low-carbon future fuel mix. Figure 1 shows the process which was applied in order to fulfil the aim of the report and meet the objectives. Firstly, an introductory review was conducted to narrow down on specific objectives within the broad aim of understanding the social acceptance landscape of biogas in Australia. Introductory reviews are useful in establishing the gap in the literature and identifying the prominent ideas that have shaped the debate so far, extend the body of knowledge in a limited way and justify the need for further research (McDougall, 2015).

Then, in Step 2, a critical interpretive review was conducted to meet the specific objectives identified in Step 1. Critical interpretive reviews are useful in answering specific questions, are thoughtfully-designed and thorough, but not always systematic as they don't review every article sourced (McDougall, 2015). Step 1 and Step 2 were conducted over several iterations. The recursive process helped in distilling researchers' reflections which enriched the final findings. Lastly, the report writing process was conducted to communicate the findings to the reader.

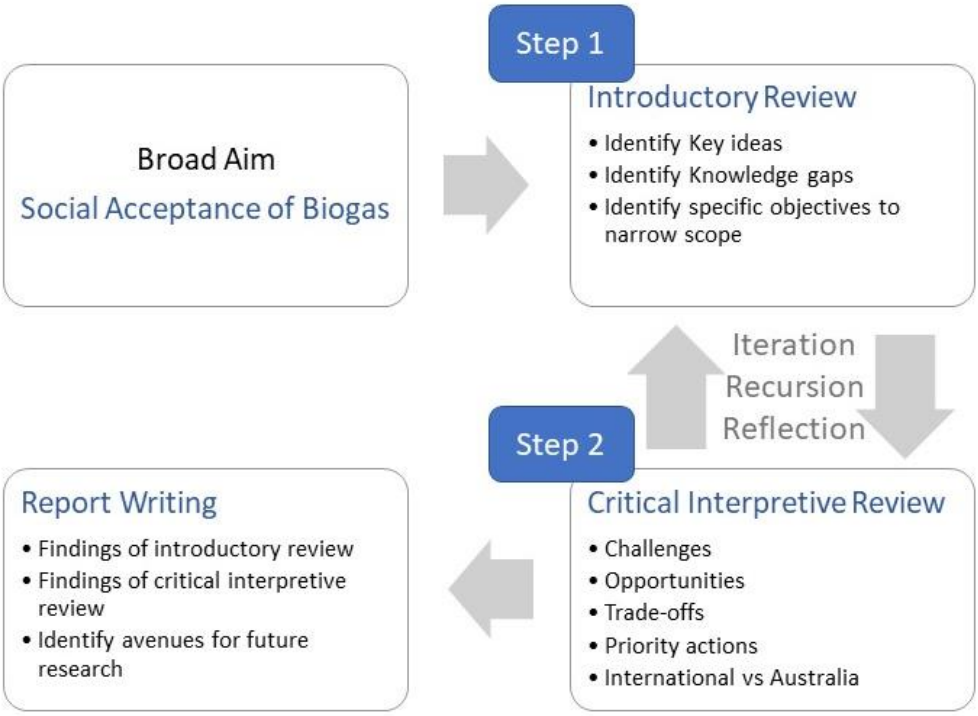


Figure 1: Literature review process

1.1. SOURCING ARTICLES

To conduct the introductory literature review, peer reviewed articles were sourced via the Web of Science (WOS). Multiple search terms relating to biogas/biomethane and commonly associated with social acceptance were used to identify relevant literature. In order to enlarge the perspective and introduce a sense of scale, the search term 'hydrogen' was also included in the search terms. Hydrogen is another prospective future fuel being investigated for its potential use in Australia. Table 1 and Table 2 show the number of articles that were found on WOS. The literature sourced via this method may refer to one or more fuel types and so may appear multiple times in every search conducted. In order to avoid repetition in the searches, a different logic was applied, relying on 'NOT' queries (Table 3 and Table 4). Tables 7 -10 show the very small number of hits returned by the database against the search queries for biogas and social acceptance.

Table 1: Overlapping results, non-exclusive research for a single Fuel Type, "all fields"

Fuel Type	biogas	Biomethane OR "Bio-Synthetic Natural Gas" OR (SNG AND Sustainable) OR Bio-SNG OR "Renewable Natural Gas"	Biomass	Biofuels	Hydrogen
+ KEY WORDS	Public; (Acceptance OR Attitude$ OR Perception$)[1]				
Number of Returned Results	61	5	313	119	237

Table 2: Overlapping results, non-exclusive research for a single Fuel Type, "topics"

Fuel Type	biogas	Biomethane OR "Bio-Synthetic Natural Gas" OR (SNG AND Sustainable) OR Bio-SNG OR "Renewable Natural Gas"	Biomass	Biofuels	Hydrogen
+ KEY WORDS	Public; (Acceptance OR Attitude$ OR Perception$)[2]				
Number of Returned Results	55	0	266	110	218

Table 3: Non-overlapping results, exclusive for a single source, "all fields"

Source	Biogas	Biomethane OR "Bio-Synthetic Natural Gas" OR (SNG AND Sustainable) OR Bio-SNG OR "Renewable Natural Gas"	Biomass	Biofuels	Hydrogen
+ KEY WORDS	Public; (Acceptance OR Attitude$ OR Perception$)				

[1] $ retrieves zero or one character in the search
[2] $ retrieves zero or one character in the search

+ NOT WORDS	Biomass; Biofuels; Hydrogen; Biomethane OR "Bio-Synthetic Natural Gas" OR (SNG AND Sustainable) OR Bio-SNG OR "Renewable Natural Gas"	biogas; Biomass; Biofuels; Hydrogen	biogas; Biofuels; Hydrogen; Biomethane OR "Bio-Synthetic Natural Gas" OR (SNG AND Sustainable) OR Bio-SNG OR "Renewable Natural Gas"	Biomass; biogas; Hydrogen; Biomethane OR "Bio-Synthetic Natural Gas" OR (SNG AND Sustainable) OR Bio-SNG OR "Renewable Natural Gas"	Biomass; Biofuels; biogas; Biomethane OR "Bio-Synthetic Natural Gas" OR (SNG AND Sustainable) OR Bio-SNG OR "Renewable Natural Gas"
Number of Returned Results	32	0	255	85	225

Table 4: Non-overlapping results, exclusive for a single source, "topics"

Source	biogas	Biomethane OR "Bio-Synthetic Natural Gas" OR (SNG AND Sustainable) OR Bio-SNG OR "Renewable Natural Gas"	Biomass	Biofuels	Hydrogen
+ KEY WORDS	Public; (Acceptance OR Attitude$ OR Perception$)				
+ NOT WORDS	Biomass; Biofuels; Hydrogen; Biomethane OR "Bio-Synthetic Natural Gas" OR (SNG AND Sustainable) OR Bio-SNG OR "Renewable Natural Gas"	biogas; Biomass; Biofuels; Hydrogen	biogas; Biofuels; Hydrogen; Biomethane OR "Bio-Synthetic Natural Gas" OR (SNG AND Sustainable) OR Bio-SNG OR "Renewable Natural Gas"	Biomass; biogas; Hydrogen; Biomethane OR "Bio-Synthetic Natural Gas" OR (SNG AND Sustainable) OR Bio-SNG OR "Renewable Natural Gas"	Biomass; Biofuels; biogas; Biomethane OR "Bio-Synthetic Natural Gas" OR (SNG AND Sustainable) OR Bio-SNG OR "Renewable Natural Gas"
Number of Returned Results	31	0	220	83	208

A graphic depiction of the search results and distribution of literature available on fuel types is presented in Figure 2. It shows that the literature that focuses on social acceptance and biogas/biomethane is scarce, almost negligible in comparison to similar articles related to hydrogen.

In order to test the maturity of the social acceptance field, another search was conducted using the search term 'safety' as it is known that safety concerns can derail the uptake of new technology projects.

Figure 3 depicts the search results and shows that literature around safety in relation to biogas/biomethane is a higher order of magnitude. Comparing Figure 2 and Figure 3, it can be confirmed that the literature on social acceptance, itself is scarce. The literature on social acceptance and biogas/biomethane, therefore is even more scarce, especially in comparison to other RE technologies including hydrogen.

These results validate previous results reported in the literature, where words in titles of the articles on biogas were graphically depicted using TagCrowd technology (Figure 4, source: (Lora Grando et al., 2017)). Figure 9 graphically depicts the words most commonly associated with biogas. The only word that can be associated with social acceptance in this figure is the word "community". The very tiny font in which this word appears is indicative of the scarcity of literature relating to social acceptance of biogas.

Based on the paucity of the literature very generous inclusion criteria were applied so that a substantive set of literature could be included into Step 2 the critical interpretive review. English language, peer-reviewed articles from reputable journals and reports from peak institutional bodies were included as the dataset for the critical interpretive review. Additional references were sourced from citations and referenced authors where a historical context was required.

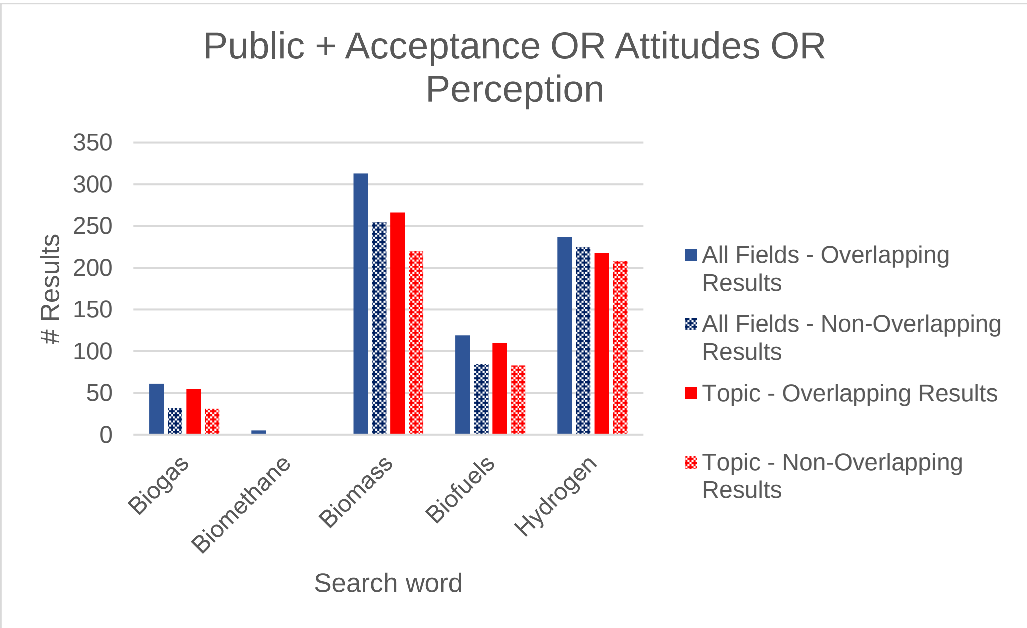


Figure 2: Results of WOS search for each technology + "Public" + ("Acceptance" OR "Attitude$" OR "Perception$")

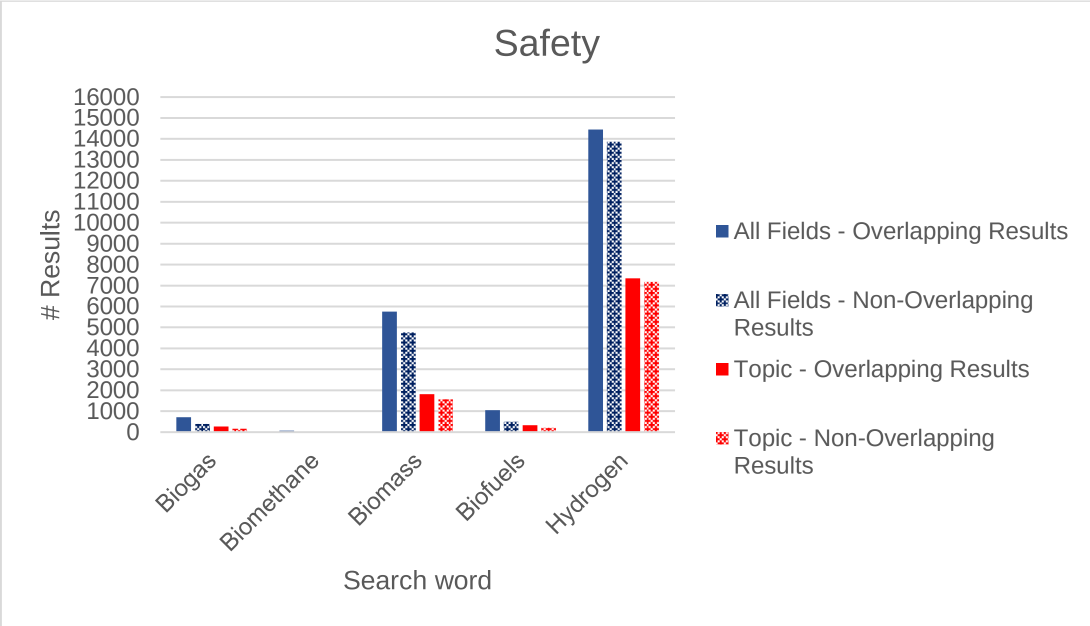


Figure 3: Results of WOS search for each technology + "Safety"

Figure 4: Word cloud for titles of articles related to biogas. Source: (Lora Grando et al., 2017), supplementary material page 1[3]

1.2. LIMITATIONS

Based on Section 1.1, it is clear that the research on social acceptance of biogas technology is at a very early stage. In the instance of 'early stages', an initial 'introductory review' was indeed appropriate and useful in building a thorough dataset for the critical interpretive review.

[3] Search terms used: biogas or "green gas" or green gas or biomethane or "digestated gas" or "renewable natural gas"; The words "biogas", "anaerobic", "production" and "digestion" are not considered in the word cloud

Subsequently, the research findings of the two-stage review process are reported in a narrative style suited to qualitative evaluation and useful in describing the key components and players within this emerging field. Narrative and descriptive reviews however, are often critiqued on grounds that a researcher's bias may creep in. This bias can seep in whilst sourcing and whilst critiquing the sourced dataset (Rother, 2007; Rowe, 2014). However, to introduce rigour into the process:

- explicit search query strings and databases have been noted in Section 1.1 to overcome reservations around bias;
- Step 1 (Introductory review) and Step 2 (critical interpretive review) were conducted in an iterative, recursive and reflective process. More than one researcher was deployed in these iterations. Iterations were repeated until a point of data saturation was reached.

3 Biogas and biomethane

Biogas is a mixture of gases generated by micro-organisms in an oxygen-free environment via anaerobic metabolism (Pain & Hepherd, 1985; Ryckebosch et al., 2011; Ward et al., 2008). Biogas production occurs as a natural process in anoxic environments such as mammalian guts, stagnated water, swamps and landfills (Piechota & Iglinski, 2021; Ward et al., 2008). It is also produced as a by-product in waste treatment plants that treat waste water, municipal biowaste such as food scraps, agricultural waste, industrial biodegradable waste and so on (Drosg et al., 2013; Ryckebosch et al., 2011; Scarlat et al., 2018). When biogas is produced through controlled anaerobic digestion (AD), a source of carbon neutral energy is produced as a co-benefit alongside the treatment of waste. Biogas is a storable and easy to handle source of energy (Gohsen & Allelein, 2015). Biogas has a methane content that typically ranges from 45% to 75%, while the rest is mostly carbon dioxide and other impurities. Biogas has a lower heating value (LHV) between 16 and 28 MJ/m^3 (IEA, 2020b).

Biogas can be upgraded, obtaining biomethane as a final product (Ryckebosch et al., 2011). By removing impurities (e.g., water, hydrogen sulphide, carbon dioxide as shown in Table 1 and reducing CO_2 content of the mixture, a higher methane content, typically around 95-97% can be achieved. Biomethane has an increased LHV of approximately 36 MJ/m3. The energy density of biogas is comparable to natural gas. Therefore, biogas can be injected into existing natural gas networks or used in transport vehicles, without any need for retrofitting (IEA, 2020b; Scarlat et al., 2018).

A range of technologies are available to produce biogas from different waste streams, each with their own advantages and disadvantages. For example, one competitive option is to recover and upgrade biogas from landfills. Biogas recovery from landfill can lower capital and operational costs (IEA, 2020b, p. 28).

Apart from landfill recovery, biogas production via AD may also be induced in industrial settings. Here, biogas production is dependent on the selection, collection and processing of suitable feedstocks (Enea Consulting, 2019). Feedstock may be solid, slurry or liquid and may include (Drosg et al., 2013; Enea Consulting, 2019; Scarlat et al., 2018):

- Industrial waste – from food and beverage processing plants (dairy, sugar, meat, pulp and paper);
- Agricultural waste – animal by-products and crop residues;
- Energy crops – like maize, silage, grass, sorghum, cereal and sugar beet;
- Sludge from waste water treatment plants (WWTP); and
- Biowaste from households, communities or small-scale commercial and industrial activities.

Each of these feedstocks differ in their water and organic-matter content. Feedstocks with high water content, low inorganic matter and low fibre are ideal for AD (Drosg et al., 2013). In turn, the physical and chemical composition of the feedstock impacts the quantity and quality of the biogas/biomethane produced (Enea Consulting, 2019). Often, due to the nature of the raw material and operating conditions, impurities may be present (

Table 5). Cleaning processes are required to turn the biogas into biomethane which has higher calorific value and adjusted chemical composition that can suit municipal gas grids and appliances (Ryckebosch et al., 2011).

Table 5: Biogas impurities and effects. Source: (Ryckebosch et al., 2011)

Impurity	Possible Effect
Water	Corrosion in components from reaction with other impurities and acid formation
Dust	Clogging due to deposition
H2S	Corrosion; toxic element
CO2	Decrease calorific value
Siloxanes	SiO2 formation and microcrystalline quartz; mechanical abrasion
NH3	Corrosion
O2/air	Explosions in higher concentrations
Cl-	Corrosion
F-	Corrosion
Hydrocarbons	Corrosion

3.1 CURRENT INTERNATIONAL PRODUCTION OF BIOGAS

Table 6presents an estimation of the annual production of biogas worldwide (World Bioenergy Association, 2020). In context of the global energy mix, biogas/biomethane meets only a fraction of total energy demand. Table 7 shows that Europe is the world leader in biogas production and Asia falls in second place.

Table 6: Global biogas production. Source: (World Bioenergy Association, 2020, p. 51)

Year	Global biogas production (billion m^3)	Global biogas production (EJ)
2000	12.4	0.29
2005	22.0	0.51
2010	37.1	0.85
2015	56.0	1.29
2016	56.6	1.30
2017	57.7	1.33
2018	59.3	1.36

Table 7: Continent wise production. Source: (World Bioenergy Association, 2020)

Continent	biogas production (billion m^3)	biogas production (EJ)
Africa	0.01	0.00
Americas	8.34	0.19
Asia	19.30	0.44
Europe	30.90	0.71
Oceania	0.84	0.02

In the European Union, the primary producers of biogas rely on different sources of feedstocks. Energy crops are the most important source for Germany and Austria; agricultural waste in Italy, Czech Republic, Denmark and Belgium; landfill in the UK, France, Poland and Spain; and organic wastes (such as municipal organic waste, wastewater and industrial slurries) in the Netherlands and Sweden (Horschig et al., 2020; Zhu et al., 2019). In contrast, the United States, Canada, China, Japan and South Korea, have a strong focus on the utilisation of waste and residues rather than energy crops.

3.1.1 Key Drivers for uptake of biogas/biomethane industry

A wide spectrum of legislation has shaped the development of the biogas sector in Europe, since energy production is not the only objective. Climate change, energy security, waste recycling, health and safety are a focus in these policies that sit at the nexus of environmental conservational, waste management, climate response and energy production (Zhu et al., 2019).

Table 8 classifies factors that have driven uptake of biogas/biomethane technologies in an international context. From an environmental and climate perspective, biogas/biomethane’s potential to reduce environmental impacts, reduce greenhouse gas emissions have been recognised and upheld in policy. Similarly, from an economic perspective, biogas/biomethane’s potential to create new jobs, new income streams, investment opportunities within a circular economy system have been recognised through economic incentives.

Aspirational targets for RE production have created fertile breeding ground for new biogas/biomethane production plants to emerge. Efficient resource and waste management through AD is recognised as a co-benefit and finds support in policies targeting efficient management of landfills and organic waste.

Table 8: Key factors that drive uptake of biogas/biomethane technology

Category	Driver	Geographic Context	Reference
Environmental conservation	waste upcycling, nutrient recycling,	Brazil, Canada, China, Germany, Japan, South Korea, Sweden UK, US	(Horschig et al., 2020; Schmid et al., 2019)
	Reduction of environmental impacts, resource efficiency	Germany, EU	(Horschig et al., 2020; Huttunen et al., 2014)
Climate response	reduction of greenhouse gas emissions	Germany, US	(Enea Consulting, 2019; Horschig et al., 2020)
Energy production	energy security/ security of supply	Germany	(Horschig et al., 2020)
Economic benefit	Economic development opportunities (jobs, new income stream, investment opportunity)	China, Denmark, France, US	(Enea Consulting, 2019; IEA Bioenergy, 2019)
	Economic incentive	Denmark	(IEA Bioenergy, 2019)
	development of local circular economy, waste as feedstock	Brazil, Canada, China, Germany, Japan, South Korea, Sweden UK, US	(Horschig et al., 2020; Schmid et al., 2019)
Policy development	Green/Renewable energy certification	Sweden, South Korea, UK	(Enea Consulting, 2019; IEA Bioenergy, 2019)
	Ambitious renewable energy targets and policy support	China, Nepal, Sweden, US, Vietnam	(Enea Consulting, 2019; IEA Bioenergy, 2019)
	Resource/ Waste management, landfill regulation (to reduce organic waste),	Brazil, Canada, China, EU, France, Germany, Japan, South Korea, Sweden, UK, US	(Enea Consulting, 2019; Huttunen et al., 2014; Schmid et al., 2019)

3.2 CURRENT DOMESTIC PRODUCTION OF BIOGAS

The Australian biogas industry is still emerging. It currently only constitutes about 0.5% of the national electricity generation mix (2016-17)(IEA Bioenergy, 2019), while the national gas market is largely reliant on *natural* gas. Figure 5 shows the sector-wide distribution of natural gas consumption in Australia. Almost three-quarters of

Australian natural gas is liquefied and exported. Industrial and residential sectors are the largest national consumers - 13 and 10 percent respectively (Figure 5).

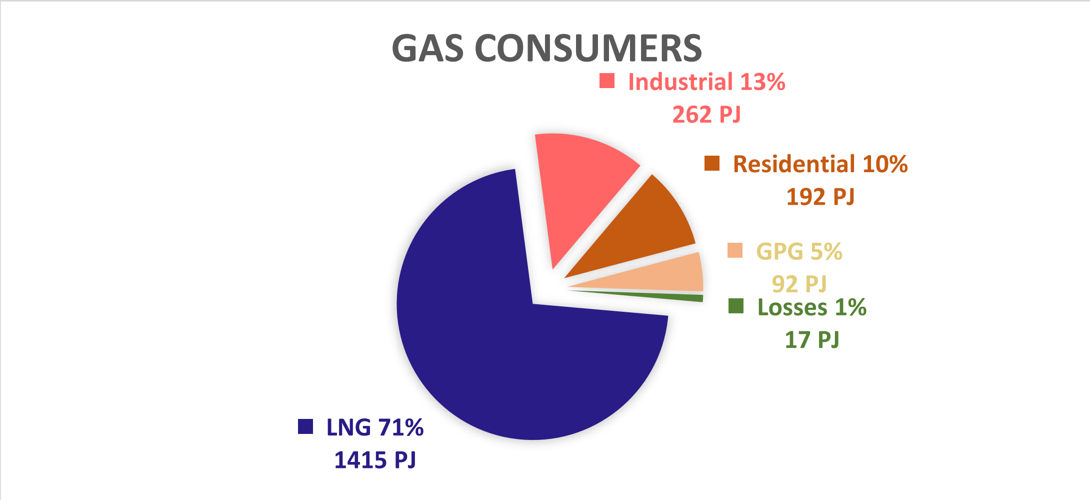
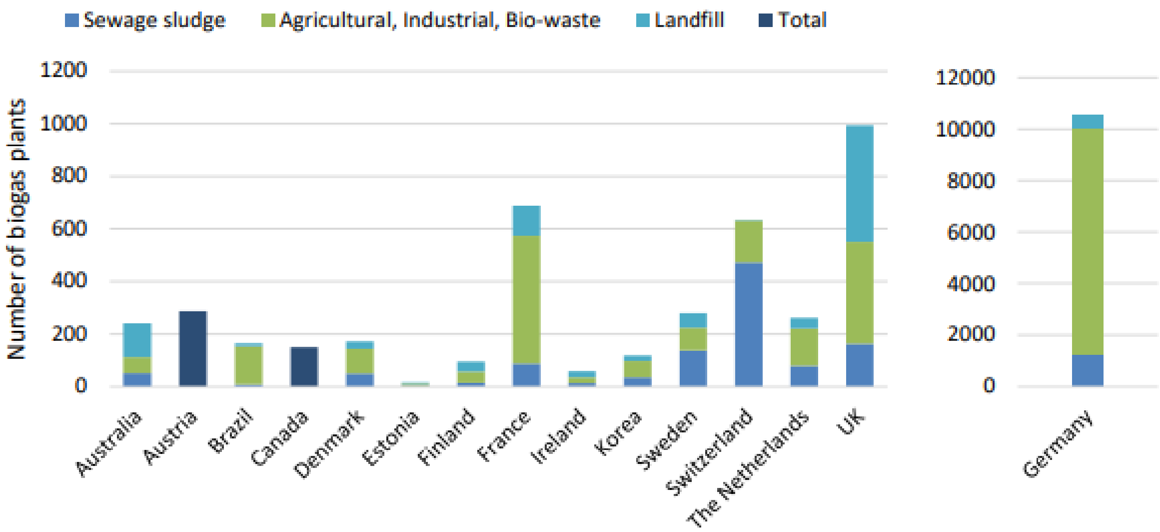


Figure 5:Australian natural gas consumption by sector. Source: (Crawford et al., 2012)

Clearly, there is scope for transitioning the current gas industry away from natural gas as this allows Australia to reduce its greenhouse gas emissions, reduce adverse environmental impacts associated with wasteful landfilling practices, establish new jobs and income streams within a circular economy system as discussed in Section 3.1.1. In addition, transitioning towards biogas, allows Australian gas grid infrastructure to remain operational in future. Especially if biomethane injection mechanisms can be devised. Secondly, there is scope to improve Australia's global standing on biogas production. Figure 6 shows where Australia stands in relation to the 19 member countries[4] of the IEA Bioenergy Task 37 - an international working group addressing the whole biogas production chain from feedstock collection and pre-treatment to biogas upgrading, biofertilizer application and process chain sustainability (IEA Bioenergy, 2019, 2020). However, it is worth noting that the current status of biogas production and biogas plants in Australia in the IEA Summary Report is based on data collected through a voluntary survey so figures may not be completely accurate (University of South Queensland, n.d.).



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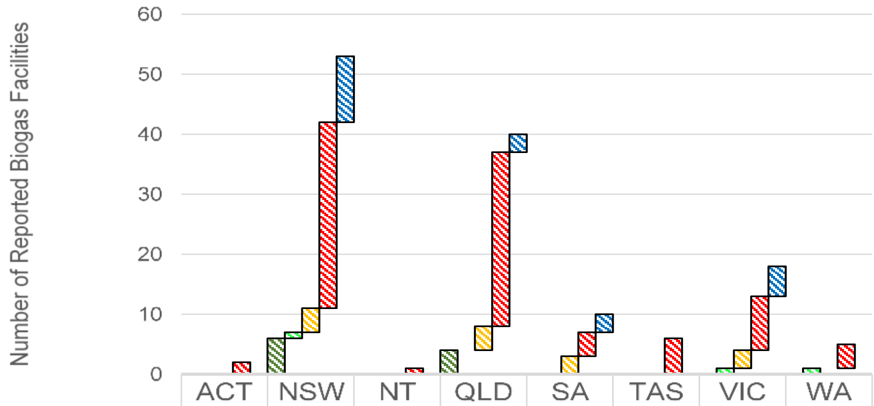
[4] Australia, China, Finland, Italy, Switzerland, Austria, Denmark, Germany, Korea, The Netherlands, Brazil, Estonia, India, Norway, United Kingdom, Canada, France, Ireland and Sweden

Figure 6: Operational biogas plants in IEA Bioenergy Task 37 member countries (2019). Source: (IEA Bioenergy, 2019, p. 3)



	ACT	NSW	NT	QLD	SA	TAS	VIC	WA
sewage		11		3	3		5	
landfill	2	31	1	29	4	6	9	4
industrial		4		4	3		3	
biowaste		1					1	1
agriculture		6		4				

Figure 7: Reported number of Australian biogas facilities by state. Source: (University of South Queensland, n.d.)

Figure 7 shows the state wide distribution of biogas plants in Australia, based on surveys conducted by the University of Southern Queensland with the support of Bioenergy Australia and ARENA (University of South Queensland, n.d.)[5]. AD plants in Australia rely mostly on WWTP for feedstock and landfill gas recovery units predominate the picture (Figure 6). Although there is insufficient data, the IEA report estimates that the main use of biogas in Australia is for electricity production, heat and combined heat and power. Currently, biogas is not used for transport in Australia nor are there any biogas upgrading facilities (IEA Bioenergy, 2019).

3.2.1 Further opportunities for biogas in Australia

Certainly, the biogas industry is in its infancy in Australia. However, understanding the biogas value chain is key to revealing opportunities and benefits for Australia. Figure **8** reveals three steps in the biogas value chain – namely, 'feedstock collection and processing', 'biogas production' and 'use' (Enea Consulting, 2019). Step 1 (feedstock collection and processing) reveals multiple benefits related to waste management, in sourcing waste as feedstock. Step 2 (biogas production) offers opportunity to obtain biogas and digestate as products. Step 3 (use) shows the benefits of biogas in heating, electricity production and biogas production. The figure also shows, the benefit of biogas used as a transport fuel and replacement fuel for injection into municipal grids. Finally, it also shows how it can be used for deploying digestate to use as fertiliser. This effectively closes the loop on waste within the agricultural sector. Another avenue of opportunity is presented when biogas is used in a cogeneration system to obtain both heat and electricity (Figure **8**).

Based on the benefits listed above, there is scope to create new jobs and diversify income streams within the Australian agricultural sector (Enea Consulting, 2019). Several reports on Australia's biogas 'potential' has indicated the opportunities for growth in jobs, investments and economic activity.

One independent study estimated the national biogas potential production to be around 371 PJ (103 TWh) – a figure that represents an estimated 102% of gas consumption from the distribution network (Deloitte, 2017). The estimates for this potential are based on biomass data, waste data and benchmark biogas yields associated with feedstock categories of urban waste, agricultural crop residue, livestock residue and food processing residue.

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[5] Last accessed 21st July 2021

Figure 9 compares the biogas potential of each of these feedstock categories. If Australia realises the estimated potential of 371 PJ, its biogas production would level with Germany's current production figures (Enea Consulting, 2019; IEA Bioenergy, 2019). However, to fulfil this potential, Australia would need another 90,000 biogas units[6] (Enea Consulting, 2019; IEA Bioenergy, 2019).

Other studies have assessed the Australian bioenergy potential at even greater values - 1,000 PJ (ClimateWorks Australia, 2014; Jacobs, 2014; Lang et al., 2014). The large difference in values that estimate 'potentials' is explained by the following facts. Firstly, as Figure **8** depicts, there are multiple steps within the biogas value chain. At each step of the value chain, an array of independent variables can be introduced that impact estimates for 'potentials'. Each of these independent variables is dependent on an array of additional variables. Multiple CSIRO studies (ClimateWorks Australia, 2014; Crawford et al., 2012; Farine et al., 2012; Graham et al., 2011; O'Connell et al., 2007) on 'potential pathways' have depicted the complexity in estimating Australia's biogas future. Clearly, there is an opportunity to gather and document accurate data relating to key variables that effect 'potentials' in order to remove the detrimental aspects of assumptions and uncertainty.

[6] Based on current average size of Australian biogas units and Australia's average annual biogas production per type of biogas unit.

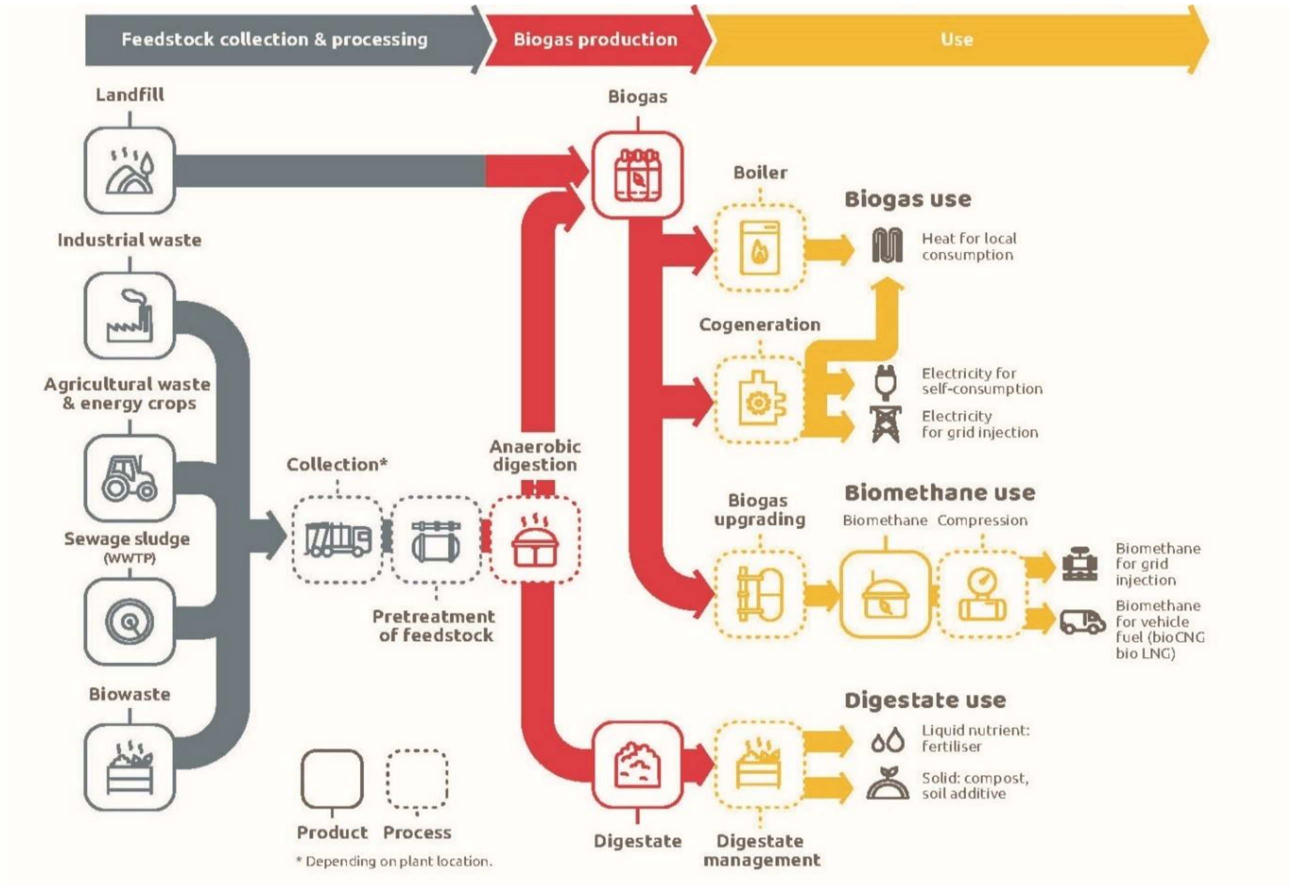

Figure 8: Biogas value chain. Source: (Enea Consulting, 2019)

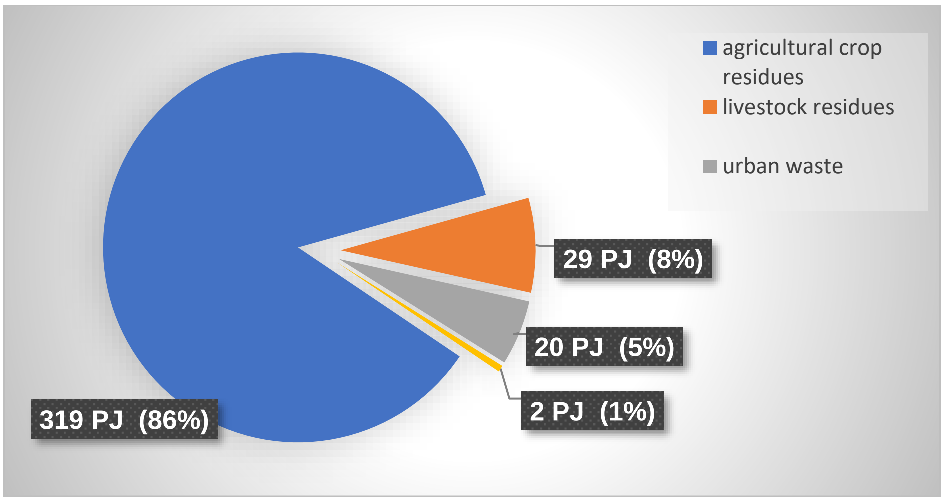

Figure 9: Breakdown of the estimated Australian biogas potential. Source: (Deloitte, 2017)

4 Barriers to adoption: what factors underpin social license?

Despite the effects of a wide-spectrum of drivers outlined in Section 3.1.1, the international biogas industry faces multiple barriers towards adoption (Table 9).Technical difficulties relating to the industrial processes, economic constraints relating to investments and finance, market forces, institutional weakness, environmental concerns and socio-cultural reticence, each have had a negative impact on the biogas industry internationally (Ammenberg et al., 2018; Nevzorova & Kutcherov, 2019; Tafdrup, 1995).

Selecting social acceptance within this range of barriers, we examined the work of scholars who explore factors that underpin socio-cultural reticence/acceptance specifically. These scholars have identified a series of social acceptance variables that may impact a RE project's fate. However, in some cases, the social acceptance variables have been shown to have a positive impact on outcomes and negative in others (Table 10).

The discussion on social acceptance therefore always highlights the importance of identifying the specific needs of the local community and then exploring how these needs can be honoured. The literature underscores repeatedly that research must allow room for sufficient context-based exploration.

In addition to social acceptance variables, safety concerns also have significant impact on outcomes. Safety concerns have been raised following accidents and mishaps. Numerous reported cases of accidents in Europe have led to some apprehension towards biodigesters [32]. For example, in Germany, in 2005, a hydrogen sulphide leak killed four people in a biogas plant facility [32, 33]. In the Netherlands, in 2012, a leak of hydrogen sulphide caused odour issues in a residential area close to a biogas plant resulting in a preventive evacuation of the local residents [32]. In another unfortunate incident in Germany, in 2015, two workers were found dead in a fermenter manhole due to exposure to toxic gases [33]. Three more fatalities were reported in Europe between 2009 and 2016, and, in total, 208 non-fatal accidents were reported in Europe between 2006 to 2016 [33].

Given that safety is a pre-requisite for social license to operate these incidents raise valid issues that will need to be overcome. It will be important to identify risks and hazards that relate to the biogas industry and ensure such knowledge feeds into health and safety standards and regulations designed to keep biogas workers, locals and communities safe.

Table 9: Identified main barriers for biogas in developed and developing countries. Source: (Nevzorova & Kutcherov, 2019)

Category	Barriers	Mostly Observed in Developed / Developing Countries
Technical	Infrastructure	Both
	Failed experience and negative image	Developing
	Need for specialised staff	Developing
	Poor waste collection and segregation	Both
	Insufficient follow-up services	Developing
	Specific characteristic of biogas (methane richness dependant on feedstock, temperature, etc)	Both
	Dependency on imported materials	Developing
Economic	High Investment	Both
	Lack of subsidies and economical support	Developing
	High cost for transporting, cleaning and upgrading biogas	Developed
	Bank loans inaccessible	Developed
	Lack of R&D	Developing

Category	Barriers	Mostly Observed in Developed / Developing Countries
Market	Lower prices of fossil fuels	Developed
	High cost of biogas/biomethane	Developed
	Competition with other fuels	Both
	Uncertainties related to the injection of biogas into the grid	Developed
Institutional	Lack of political support	Developing
	Uncertain policy landscape	Developed
	Lack of coordination between private and public sectors and lack of participation from the former	Both
	Bureaucracy	Developed
Socio-cultural	Lack of public and consumer interest	Both
	Desire to maintain the status quo	Developing
	Low level of knowledge	Both
	Lack of information available	Developing
	Low level of education/literacy rate	Developing
	Cultural and religious outlook	Developing
	Migration from the countryside to cities	Developing
Environmental	Odours	Developed
	Noise	Developed
	Need for abundant water resources / Lack of access to adequate water	Developing
	Pollution	Developed

Table 10: Factors underpinning social acceptance in an international context

Social Acceptance Variables	Influence and direction	Reference
General attitude towards power generation from biomass	Positive	(Dobers, 2019; Soland et al., 2013)
RE advocacy	Positive	(Schumacher & Schultmann, 2017)
General attitude towards energy crops	Positive	(Dobers, 2019)
Place attachment	Neutral	(Dobers, 2019)
Spatial proximity to RE projects	Negative	(Dobers, 2019; Schumacher & Schultmann, 2017)
Intensity of energy crop cultivation	Negative	(Dobers, 2019)
Distributive Justice		

Social Acceptance Variables	Influence and direction	Reference
Perceived benefits	Positive	(Schumacher & Schultmann, 2017; Soland et al., 2013)
Perceived costs	Neutral	(Schumacher & Schultmann, 2017)
Perceived odour	Mixed result	(Schumacher & Schultmann, 2017; Soland et al., 2013)
Procedural Justice		
Trust in the plant operator	Positive	(Schumacher & Schultmann, 2017; Soland et al., 2013)
Information offer Quality of information Timing of information	Neutral Positive Neutral	(Schumacher & Schultmann, 2017) (Nevzorova & Kutcherov, 2019; Soland et al., 2013) (Soland et al., 2013)
Participation option	Neutral Positive	(Schumacher & Schultmann, 2017; Soland et al., 2013) (Nevzorova & Kutcherov, 2019)

5 Review findings

The specific objectives of the report were to i) identify challenges, opportunities, trade-offs and priority actions that have emerged from the experience of other nations; ii) how these experiences may inform Australia's transition to a low-carbon energy future in relying on biogas/biomethane as an option within the future energy mix.

To meet these objectives, the findings first evaluate existing knowledge frameworks around the prospect of social acceptance for biogas in Australia. Existing knowledge frameworks bear two aspects: a 'descriptive' aspect and a thematic aspect. The descriptive aspect is reported in Section 5.1 and shows where the geographical focus and subject focus of current research sits.

Next, the thematic aspects are explored. In order to do so, the report takes the following route:

- Synthesises a framework for social acceptance based on the descriptive findings which in turn are based on the knowledge frameworks sourced from the literature (Section 5.2). A conceptual framework of social acceptance is necessary to construct a sound theoretical basis for future work that results from this review. Knowledge gaps and prospects for new knowledge creation are situated within the conceptual framework.

5.1 SORTING AND CLASSIFYING THE LITERATURE

To understand more from the literature, firstly, the geographical focus of current research was determined. To do this literature selected for the review was sorted based on the following parameters:

- Studies relating to RE, and/or biogas and their general technical, industrial, process chain aspects pertaining to countries across more than one continent, were tagged as 'global' studies.
- Theoretical literature pertaining to the concept of social acceptance were also tagged as 'global'.
- Case studies relating to specific countries, regions and/or cities were tagged with name of the continent in which those locations exist.

By doing so, it was found that work from Europe dominates the discussion. However, multiple studies with an international focus were also found (and tagged as global). The search queries returned minimal publications from Asia/ Africa and Americas. Earlier studies have also commented on the fact that literature (on social acceptance of biogas) largely relates to the experience of the European nations and less so on Asia and other parts of the world (Radics et al., 2015). Since Australia, was a focus, multiple reports on the potential future of the biogas industry were included in the review. The geographical focus of the selected literature is summarised in Table 11.

Table 11: Geographical Distribution of Literature

Continent	References	No. of References
Global	(Balat & Balat, 2009; Cucchiella & D'Adamo, 2016; Drosg et al., 2013; Gohsen & Allelein, 2015; Gunningham et al., 2004; IEA, 2020a, 2020b; IEA Bioenergy, 2019, 2020; Nevzorova & Kutcherov, 2019; Radics et al., 2015; Ryckebosch et al., 2011; Schmid et al., 2019; Ward et al., 2008; World Bioenergy Association, 2020; Wüstenhagen et al., 2007)	16
Europe	(Ammenberg et al., 2018; Bendixen, 1994; Chodkowska-Miszczuk et al., 2020; Cicia et al., 2012; Dahlin et al., 2015; Dobers, 2019; Eker & van Daalen, 2015; Herbes et al., 2018; Herbes et al.,	25

Continent	References	No. of References
	2014; Hoppe & Sanders, 2014; Horschig et al., 2020; Huttunen et al., 2014; Lora Grando et al., 2017; Lund et al., 1996; Magnani, 2012; Pain & Hepherd, 1985; Piechota & Iglinski, 2021; Sahlström, 2003; Scarlat et al., 2018; Schumacher & Schultmann, 2017; Segreto et al., 2020; Soland et al., 2013; Tafdrup, 1995; Trávníček et al., 2018; Upreti & van der Horst, 2004; Zhu et al., 2019)	
Australia	(AEMO, 2020; ClimateWorks Australia, 2014; Deloitte, 2017; Enea Consulting, 2019; Hall et al., 2013; Jacobs, 2014; Lang et al., 2014; Martin & Rice, 2015; University of South Queensland, n.d.)	9
Africa	(Kwaku Armah et al., 2017)	1
Americas	(Aguilar & Cai, 2010)	1

In the next step, literature was sorted based on its subject focus. Titles, abstracts, introductions and conclusions were manually scanned in that order to determine the key concepts embodied in each piece. Where multiple key concepts were indicated, full articles were read, so that they could be tagged appropriately. By sorting the literature this way, it was possible to determine key concepts and define broad themes to include in the report. identifies the emergent key concepts.

Table 12: Subject Focus

Subject	References	No. of References
Forecasting Potentials Opportunities Barriers	(AEMO, 2020; Balat & Balat, 2009; ClimateWorks Australia, 2014; Cucchiella & D'Adamo, 2016; Deloitte, 2017; Enea Consulting, 2019; IEA, 2020a, 2020b; IEA Bioenergy, 2019, 2020; Jacobs, 2014; Lang et al., 2014; Martin & Rice, 2015; Nevzorova & Kutcherov, 2019; Piechota & Iglinski, 2021; Scarlat et al., 2018; Tafdrup, 1995; World Bioenergy Association, 2020; Zhu et al., 2019)	18
Social Acceptance	(Cicia et al., 2012; Dahlin et al., 2015; Dobers, 2019; Gunningham et al., 2004; Hall et al., 2013; Herbes et al., 2018; Magnani, 2012; Radics et al., 2015; Schumacher & Schultmann, 2017; Segreto et al., 2020; Soland et al., 2013; Upreti & van der Horst, 2004; Wüstenhagen et al., 2007)	12
Technology	(Bendixen, 1994; Drosg et al., 2013; Kwaku Armah et al., 2017; Lora Grando et al., 2017; Lund et al., 1996; Mata-Alvarez, 2002; Pain & Hepherd, 1985; Ryckebosch et al., 2011; University of South Queensland, n.d.; Ward et al., 2008)	10
Policy Drivers Stakeholders	(Ammenberg et al., 2018; Chodkowska-Miszczuk et al., 2020; Eker & van Daalen, 2015; Hoppe & Sanders, 2014; Horschig et	7

	al., 2020; Huttunen et al., 2014; Schmid et al., 2019)	
Market Forces	(Aguilar & Cai, 2010; Gohsen & Allelein, 2015)	2
Safety Risk	(Sahlström, 2003; Trávníček et al., 2018)	2

Lastly, sub themes were identified within the respective subject focus areas and classified in Table 13. Sub-themes often crossed over in relation to other subjects (classified in Table 12). Understanding these cross over relationships was helpful in constructing the conceptual framework for the remainder of the report (Section 5.2).

Table 13: Thematic Classification of Literature

Theme	Sub-Theme	Locational context	Reference
Barrier towards acceptance	Energy crops	Italy	(Cicia et al., 2012)
	Digestate	European Union (EU)	(Dahlin et al., 2015)
	Biomethane	France	(Herbes et al., 2018)
Opportunity	Digestate marketing	EU	(Dahlin et al., 2015)
	Biomethane marketing	France	(Herbes et al., 2018)
Social acceptance Variables	Attitudes Place attachment Spatial Variables	Germany	(Dobers, 2019)
	Trust Place attachment Distributional justice Procedural justice	Australia	(Hall et al., 2013)
	Distributional justice Procedural justice	Italy	(Magnani, 2012)
	Advocacy Perceived benefits Perceived costs Trust Information and participation Spatial variables	Germany, France, Switzerland	(Schumacher & Schultmann, 2017)
	Trust Distributional justice Procedural justice Spatial Variables Socio-demographics	Europe	(Segreto et al., 2020)
	Perceived Benefit Perceived costs Information Distributional justice Information Participation	Switzerland	(Soland et al., 2013)
Social Licence	Theory and conceptual framework	Global	(Gunningham et al., 2004;

Theme	Sub-Theme	Locational context	Reference
			Wüstenhagen et al., 2007)
Awareness and Relationship building	Communication strategies	France	(Herbes et al., 2018)
	Communication strategies	UK	(Upreti & van der Horst, 2004)
	biogas Information management strategies	Germany, France, Switzerland	(Schumacher & Schultmann, 2017)
Policy Implications	Wind farms	Australia	(Hall et al., 2013)
	Biomethane	France	(Herbes et al., 2018)
	biogas Plants	Italy	(Magnani, 2012)
	RE systems	Europe	(Segreto et al., 2020)
	biogas plants	Switzerland	(Soland et al., 2013)
Stakeholders	Groups and perception	Global	(Radics et al., 2015)

5.2 A THEORETICAL FRAMEWORK FOR SOCIAL ACCEPTANCE

In this section, the report constructs a theoretical framework to conceptualise how the descriptive findings sit in context to each other. To graphically depict the framework, a concept map is created. The concept map is informed by established theory (Gunningham et al., 2004; Wüstenhagen et al., 2007). It draws upon the most popular variables – which repeatedly appear in international social acceptance research (Table 10), subjects (Table 12) themes and sub-themes (Table 13) reported in Section 5.1. The theoretical framework embodied in the concept map (Figure 10) is useful in providing a structure within which to report the thematic findings. However, the components displayed herein are an indicative list and not an exhaustive list.

5.2.1 Social acceptance

At the outset, Figure 10 seeks to explain social acceptance from a theoretical perspective. It is understood that social acceptance has three facets. Namely, community acceptance, market acceptance and socio-political acceptance (Wüstenhagen et al., 2007). Examining each of these facets individually, key players may be identified in each specific case. Each of these key players may lend their voices within an acceptance debate, may share information amongst each other, influence or drive the discussion in specific ways, and effect outcomes to varying degrees. Generalisations are difficult as each social acceptance case study has shown that broader socio-cultural variables, geographic context, and scale each have a role to play.

Next, a series of variables may be identified against each of the three facets of social acceptance (community, market and socio-political). Each of these variables are interdependent and bear influence on what information is shared across them. The type and quality of information available to the range of key players bears an influence on how they perceive and ultimately accept or resist a specific RE technology. This phenomena of acceptance or resistance, as the case maybe, in turn bears influence upon how policy and communication strategies may be framed.

Each case study included in the review conforms to this pattern of storytelling. However, the permutation and combination of variables included and the reported interdependencies may vary. Next, the report narrows in on biogas/biomethane technologies, selects and highlights the key themes that have framed the debate internationally. On the basis of literature, key stakeholders within this debate have been identified as follows:

5.2.2 Key Stakeholders

Key stakeholders who may influence social acceptance debates maybe classified based on their association with communities, markets and/or socio-political associations. Figure 10 presents an indicative list of groups within the broad classification. Based on the literature, these groups can be further refined based on other factors.

For example, the biogas value chain often competes with other utilisation pathways like food, livestock feed, or material usage sector; interacts with further sectors like forestry or waste management. Moreover, it may have diverse ecological impacts and so varying influence on sustainable development. It comprises a large variety of usable feedstock. Various conversion pathways maybe involved. Energy carriers and value-added chains are diverse. Each of these factors, brings to the forefront numerous actors, who become influential in social acceptance debates relating to biogas/biomethane (Schmid et al., 2019).

Examining the literature, it is seen that stakeholder identification is also dependent on the specific aims and objectives related to each research study. For example, in a regional green gas project context, one study identifies five stakeholders as relevant within the scope of its research on the agricultural sector in Netherlands: (i) biogas producers, (ii) the gas grid operator, (iii) the energy supply company, (iv) end-consumers, and (v) local government (Hoppe & Sanders, 2014). Another study on regional gas transition included perspectives of biogas plants operators, farm owners, representatives of local authorities and local companies and residents; and indicated that inclusion of public, private, NGOs and citizen organizations within the debate could minimise the risk of peripheralization in the case of Central European countries (Chodkowska-Miszczuk et al., 2020). A German study identifies and classifies a wide-spectrum of stakeholders along an interest-influence matrix (Horschig et al., 2020). Based on the matrix, the study tags 'key players' as those who can control outcomes, namely (i) policy makers, on European, national and state level, for example ministries for agriculture, who set the framework of governance; (ii) powerful interest groups such as biogas or farmers associations and (iii) environmental NGOs who exert pressure for stricter sustainability regulations to counteract perceived loss of biodiversity related to large energy crop use. When the context is urban transport and biogas, other public organizations that may play a key role include public transport organisations/authorities, taxi companies, municipal wastewater treatment plants and municipalities (Ammenberg et al., 2018).

Since in Australia, maximum volumes of biogas are captured at landfills, landfill operators may play a key role when it comes to developing infrastructure to capture, process and inject biomethane. In Australia, local councils and/or private companies manage operations at landfills. Cryogenic treatment is a promising technology as a cost-effective solution for producing high methane purity, especially well-suited for landfill gas treatment (Enea Consulting, 2019). In Europe, the technology is being demonstrated in a few pilot plants and commercial plants. These pilot and commercial plant operators may hold knowledge that is key in developing Australia's capability in landfill gas treatment. Although there is currently no biogas upgrading plant in Australia, some international providers are already present, such as Greenlane Biogas (New-Zealand company) or Hitachi Zosen Inova (Swiss company with an Australian office) (Enea Consulting, 2019). As pioneers in the industry, these companies and others who hold knowledge and experience in cryogenic treatments may come to play a key role in the future. Other biogas producers in Australia process sewage sludge (WWTPs), industrial waste, agricultural and biowaste. Stakeholders related to these industries will each have nuanced perspectives that contribute to the social acceptance debate in Australia. As has been evidenced in Europe, these issues may be related to the biogas value chain; and/or issues arising from sustainable regional, urban, peri-urban development; and/or social justice criteria.

The literature reviewed up to this point has been useful in indicating how selection criteria have been framed abroad to identify relevant stakeholders. However, more research is required to comprehensively frame detailed selection criteria and construct a more holistic list of prospective key stakeholders in relation to specific research aims and objectives in the Australian context.

Next, the role of key players, based on selected examples, is explained to show how social acceptance, market and socio-political variable interact (Section 5.2.3.).

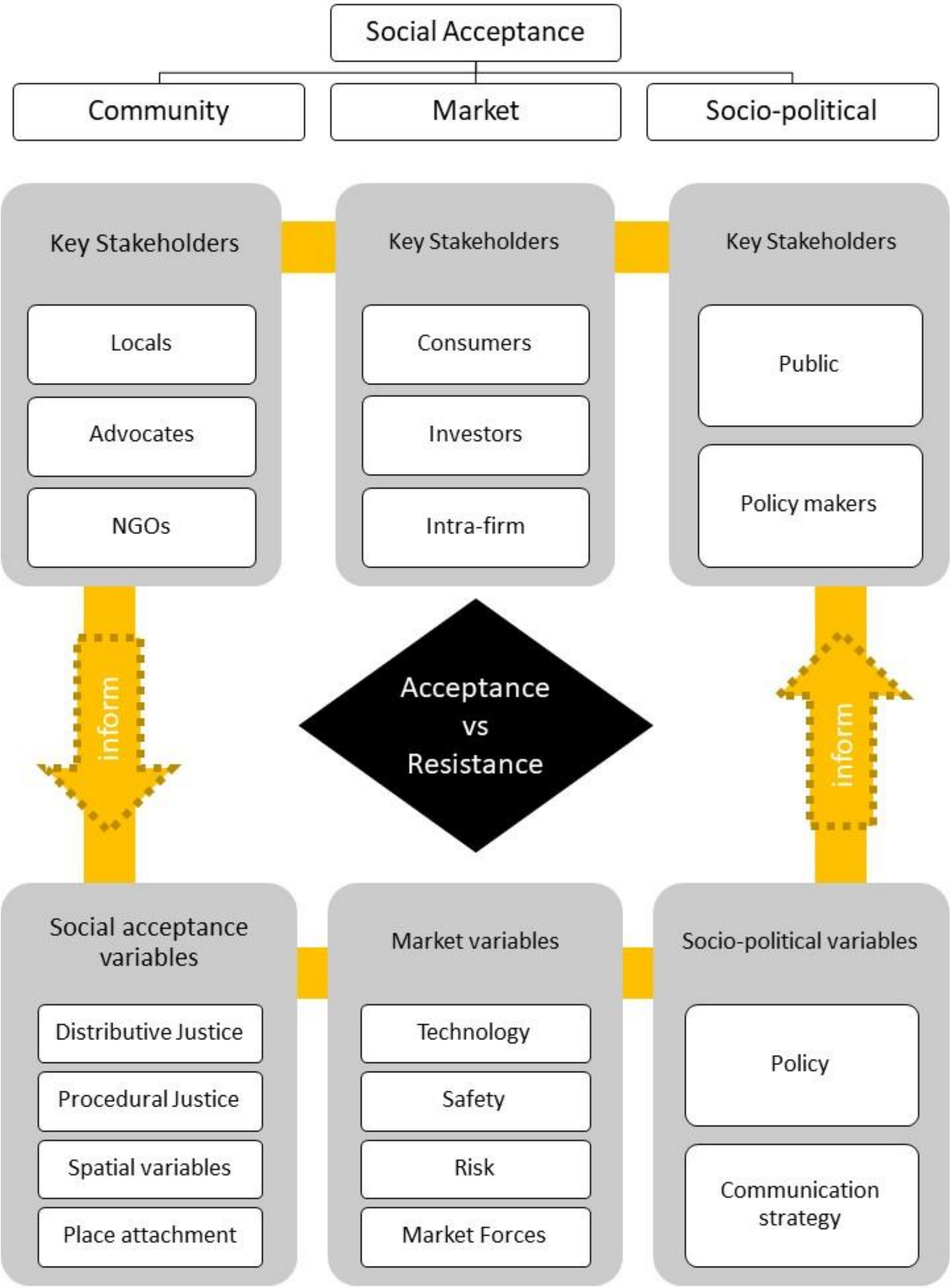

Figure 10: Concept Map - A theoretical framework to explain social acceptance

5.2.3 Juxtaposition of social acceptance variables against market and socio-political variables

5.2.3.1 Social Acceptance variables

In Europe, there appears to be wider public support for biogas/biomethane since there is awareness around the environmental benefits associated with AD on carbon emissions, waste treatment, pollution reduction, energy production, and improvements in agricultural practices (Herbes et al., 2018; Tafdrup, 1995; Zhu et al., 2019).

Advocacy towards renewable energies and trust amongst stakeholders, are seen to act as drivers of acceptance (Herbes et al., 2018; Schumacher & Schultmann, 2017). On the other hand, if general public knowledge towards biogas and biomethane is scarce then it acts as a barrier towards acceptance (Herbes et al., 2018; Nevzorova & Kutcherov, 2019; Tafdrup, 1995). Often, lack of knowledge or misconceptions about biogas/ biomethane persist regardless of the educational level of the public (Herbes et al., 2018). For example, a French study on consumers' perception on biomethane included interviewees who were better educated than the average French citizen and yet discovered that consumers' labour under misconceptions regarding the costs of biomethane production (Herbes et al., 2018). The study highlights the importance of addressing consumers' low level of knowledge and high level of mistrust in order to facilitate uptake.

Often, issues around distributive justice have also arisen and acted as barriers towards acceptance. For example, consider the case of energy crops being used as feedstock in Germany and France. Negative perceptions of crops to energy projects (compared to wastewater and agricultural waste) were observed since energy crops were seen as a threat to global food and water security (Herbes et al., 2018; Horschig et al., 2020). Other issues around distributive justice include issues of odours arising from the projects and impacting neighbours and aesthetics. Odours associated with biogas facilities were perceived to decrease property values. This fed into concerns regarding siting and ultimately feasibility of the biogas projects (Segreto et al., 2020; Soland et al., 2013). In the Netherlands, several biogas plants faced opposition from local communities who raised concerns around the industrial plant's aesthetics, loss of scenic amenity to their locality, and increased transport movement which were seen to negatively impact them (Hoppe & Sanders, 2014).

The issue of procedural justice has also acted as a barrier towards acceptance. In one Italian alpine community, heavy objections were raised against a biogas project. The community highlighted their lack of involvement in the planning process and objected against the secrecy surrounding all key aspects of the project - its characteristics, (identities of) the farmers involved, technological and market risks (Magnani, 2012).

5.2.3.2 Market variables

A range of actors are involved in the European biogas market including input suppliers, biogas producers and suppliers, gas grid operators, customers, sector organizations, public authorities and academia (Hoppe & Sanders, 2014; Zhu et al., 2019). The cost of biogas production has a dependency on feedstock availability, location and plant size – factors that reduce its competitiveness against fossil fuels (IEA, 2020b; Tafdrup, 1995; Zhu et al., 2019). In order to succeed, therefore public subsidies are almost always needed (see Section 5.2.3.3).

However, biogas facilities can control their electricity production through their storage capability and flexibility in operation in time, duration and amount. For this reason they may be a safe and efficient RE option for electricity production in response to short and long-term market signals (Gohsen & Allelein, 2015).

Digestate, a waste product of AD is also a potential candidate to add value in the biogas process supply chain as a substitute for mineral fertiliser. However, it may face opposition on the grounds of, chemistry, safety, effectiveness as fertiliser and difficulties related to its management, handling and transport (Huttunen et al., 2014; Magnani, 2012). It may also face opposition on grounds of religion, since digestate processed from pig slurry cannot be marketed to Islamic communities (Dahlin et al., 2015).

5.2.3.3 Socio-political variables: the role of policy

In European countries like Germany, Sweden, Switzerland, France, Netherlands, Denmark, Ireland and in the UK, biogas adoption and development has been facilitated due to the positive action of governments and pubic authorities like the European Commission, Member State governments, local authorities and municipalities. Each of these agencies act in alignment, making national plans, establishing subsidy support (IEA, 2020b) and backing the ambitions set out by the European Commission and Parliament (Ammenberg et al., 2018; Zhu et al., 2019). However, currently the European Union's biogas projects are firmly dependent on subsidies and other policies to be cost competitive (Cucchiella & D'Adamo, 2016; Eker & van Daalen, 2015; Scarlat et al., 2018; Zhu et al., 2019). When subsidy support is removed, the economic feasibility of the biogas plant is questionable. A case in point is that of the Czech Republic. No new plants have been built in the Czech Republic since 2013, once the government there stopped its financial assistance plan for new biogas plants (Chodkowska-Miszczuk et al., 2020).

In the next section we show how information flows between each of the stakeholders can influence actions and outcomes.

5.2.4 Information flows and communication strategies

Studies have shown that information flows can greatly influence the success or failure of biogas projects (Magnani, 2012; Soland et al., 2013; Upreti & van der Horst, 2004). For example, a Swiss survey found that local acceptance of biogas plants was influenced by information circulated during the planning and development process (Soland et al., 2013). The study explains that persons who reported that they were informed and involved showed higher levels of perceived benefits and lower levels of perceived costs. The study found it was useful to raise awareness of the possible benefits and also reduces concerns about possible costs of the biogas plant during the planning/development phase. High quality-information was found key to building trust amongst stakeholders in this study.

Also seen as useful, is the inclusion of different information and viewpoints sourced from both a lay and expert perspective (Magnani, 2012). For example, a deeply critical debate in an Italian alpine community was facilitated with information contributed by a variety of experts - economists, agronomists, engineers, local farmers union leaders national trade union organizations and socialists who considered the environmental and social effects of producing energy from agricultural biomasses by means of a large, centralized biogas plant in a mountain valley municipality. Following deliberations, locals were able to challenge the provincial administration's vision of a large biogas plants as a solution to reduce environmental pollution from local intensive dairy farming. Instead, based on their nuanced discussion, other sustainable development scenarios emerged which were embedded in local socio-ecological systems and sensitive to the needs and characteristics of the local community.

Lack of information has been linked to failed development in another case - North Wiltshire, UK where Ambient Energy Ltd. proposed the development of a wood gasification plant near the town of Cricklade (Upreti & van der Horst, 2004). In this case, the authors attribute the failure of the plant to two distinctly rigid characteristics among the key stakeholders of biomass energy development - the 'not-in-my-back-yard' attitude from the public versus the 'there-is-no-alternative' attitude of the developers. The authors highlight the need for interaction and dialogue with public, proper information dissemination from the beginning and awareness raising in order to reduce public perception of risk. Local perception of the risks related to emissions, environment, pollution, traffic generation, and technical assessment led to strong public opposition in the North Wiltshire case. Lack of information and interaction created misunderstanding, raised suspicions and lowered trust amongst the stakeholders. The economic advantage of the developer was seen to be in conflict with local aspirations for environmental protection and scenic amenity and so the project failed.

Based on a comparative study of trinational (Germany, France, Switzerland) Upper Rhine Region, the importance of classifying stakeholder groups as supportive/unsupportive/undecided is revealed. The authors highlight the importance of developing specific communication strategies for each stakeholder groups so as to address the expectations and conditions under which the groups are willing to accept a local biogas plant (Schumacher & Schultmann, 2017).

In the next chapter, the findings of the review are summarised and implications and recommendations are explored.

6. Conclusions implications, research gaps and prospects for new knowledge

The findings outlined in this report are largely informed by the European experience. However, there is a biogas industry that is well established in Asia and Americas (IEA, 2020b; World Bioenergy Association, 2020). This review struggled to find literature on social acceptance in these parts of the world. However, it might be useful to understand how the socio-techno-political systems have developed in these nations and whether any lessons learnt, could be useful in informing the Australian experience.

Focusing on the social acceptance aspect in Australia: there is literature around outlooks and the potential of biogas/biomethane (AEMO, 2020; Deloitte, 2017; Enea Consulting, 2019; Lang et al., 2014), driven by the debate around targets for decarbonisation and improvements needed in RE policy (ClimateWorks Australia, 2014; Jacobs, 2014; Martin & Rice, 2015). To this end, work on social acceptance of a wide range of RE technology has commenced (Hall et al., 2013). However, the social acceptance aspect of biogas/biomethane is yet to be explored. The role of social licence and social acceptance is well understood and the call for rigorous stakeholder engagement has been made (Enea Consulting, 2019). To this end, the prospects for research are promising as there is a lot of ground to cover. Surveys, qualitative interviews, deliberative engagement panels have shown their effectiveness in the reviewed literature and offer sound methodologies to trial in detecting the Australian psyche surrounding a biogas industry.

The drivers and barriers from European case studies along with the social acceptance, market and socio-political variables known to hold influence have been identified to help inform research in this area. However, the literature has shown the interdependencies of these variables can shift, based on scale and context. Future research needs to focus on the Australian case, specifically identifying the interdependencies and shifts, consider all variables related to scale (national, regional, local, rural, urban and peri-urban) and context (where, when, how, and who for). Once these interdependencies and shifts are known, communication and engagement strategies can be built that manage subsequent information flows effectively amongst the stakeholder groups based on their specific values, interests and preferences. From the European experience it is known that when information flows highlight the co-benefits of the biogas process supply chain (such as environmental benefits, waste management, diversification in agricultural income, low-carbon fuel for transport, and digestate as fertiliser), acceptance has been nurtured over time.

Despite these benefits however, biogas/biomethane has relied heavily on public subsidies to be cost competitive in Europe. Therefore, Australian federal and state governments, local city councils, producers, consumers, and gas grid operators, will all need to be engaged at the outset to determine their acceptance levels and willingness to embrace biogas/biomethane. Once issues have been identified, they need to be addressed in a unified approach so that a sensitive, self-aware, socio-techno-politically sound policy landscape can emerge. Sound policies, regulations, technical standards are a must-have to ensure long term safety and security for everyone involved.

This literature review clearly shows that there is benefit and scope in pursuing more detailed studies around the social acceptance of biogas.

6.1. RECCOMENDATION FOR INDUSTRY

The review undertaken thus far, has justified the case for investigating the Australia public's response to biogas today. The conceptual framework of social acceptance of biogas/biomethane in Australia can be built up based on Figure 10 and there is scope to further refine and expand this conceptual framework based on other social acceptance and social licence to operate models; and nuances of:

- scale – whether national, regional, local, rural, urban and peri-urban;
- context – where, when, how, and who for; and
- findings reported in past studies on Australians' social acceptance of other RE technologies.

In the first instance the research might include interviews with key stakeholders from the existing industry and focus groups and a national survey of the general public to better understand current responses to the concept of biogas/biomethane. The findings arising from such research will help to contribute in real terms to policies and engagement strategies around Australia's low-carbon future fuel mix.

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Appendix: Normative definitions

Anaerobic digestion	fermentation of organic matter in the absence of oxygen (Deloitte, 2017)
Biogas	Biogas is a mixture of gases generated by micro-organisms in an oxygen-free environment via anaerobic metabolism (Pain & Hepherd, 1985; Ryckebosch et al., 2011; Ward et al., 2008)
Bioenergy	Bioenergy refers to the use of biological commodity (or biomass) used specifically for energy purposes. The energy use implies the use of biomass for electricity and heat generation and the conversion of biomass to secondary products such as biofuels to be used in the transportation sector. For bioenergy, the energy content of the fuel is considered as primary energy (Lang et al., 2014; World Bioenergy Association, 2020)
Biofuel	Transport fuel derived from biomass is known as Biofuel. In Australia, biofuels for transport represent a small proportion of Australia's bioenergy. Ethanol is produced from sugar by-products, waste starch and grain. Biodiesel is produced from used cooking oils, tallow from abattoirs and oilseeds(Lang et al., 2014)
Biomass	Biomass is a biological commodity. In Australia, four types of biomass can contribute to the bioenergy sector (Lang et al., 2014): a) Woody biomass as residues and wastes from forestry, plantations, woody weeds, woody energy crops, timber industry processing and urban wood wastes and suitable as fuel for furnaces; b) Agricultural straw and stalk and other residues, like husks and hulls, and 'dry' ligno-cellulosic material that can be gathered, compacted for transport, and used to fuel a furnace; c) Municipal 'dry' wastes that have had recyclables, hazardous and non-combustible material removed. This combustible municipal waste material is generally about 60–70 % biomass and is suitable for a waste to energy (WTE) pathway; Putrescible wastes suitable for anaerobic digestion to produce biogas. This includes sewage, animal manures, food processing residues and waste food, and high moisture content green waste
Biomethane	Biomethane is produced when impurities from biogas are removed (Ryckebosch et al., 2011)
Biosynthetic natural gas (bioSNG)	bioSNG is a gas produced from methanation of synthetic natural gas.
Gasification	Gasification is a thermal process through which a solid fuel stock is converted into a combustible gas which can be used as an energy source. Dehydrated coal, steam and oxygen are combined under heat and pressure (often in the presence of a catalyst to improve efficiency and promote creation of desired compounds14) to produce a synthesis gas (also referred to as syngas). The syngas comprises hydrogen gas along with carbon monoxide and carbon dioxide (Deloitte, 2017)
GPG	Gas-powered generation of electricity (AEMO, 2021)
Green gas	A synonym for biomethane (Enea Consulting, 2019)
LNG	Liquefied natural gas (AEMO, 2021)
LPG	Liquefied petroleum gas
Methanation	The conversion of carbon monoxide and carbon dioxide to methane through hydrogenation
Natural gas	Gas comprised of mainly methane and hydrocarbons used to produce heat for cooking, heating and industrial processes (Deloitte, 2017)
SNG/ Syn-gas	Synthesis natural gas is a gas produced from gasification of biomass (Lang et al., 2014)
Renewable natural gas	A popular synonym for biomethane in North American countries (Schmid et al., 2019)
PJ	Petajoules a unit of measure for energy and work)
TWh	Tera Watt Hour is a composite unit of energy and refers to getting power at a capacity of 1 terawatt (10^12 watts) for one hour
Waste to energy (WTE)	Waste to energy involves direct combustion of waste. Also known as biomass combustion or waste incineration (Enea Consulting, 2019).

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