Investigating the biogas potential from organic waste flows in Santiago de Chile

– A study of the Metropolitan Region

Filippa Bengtsson

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Undersökning av biogaspotentialen från organiskt avfall i Santiago de Chile.
– En studie av den Metropoliska Regionen.

Sammandrag

I den Metropoliska Regionen i Chile växer befolkningsmängden när landet genomgår urbanisering och invånarna flyttar till huvudstaden Santiago de Chile. Belägen i en dal där nu över 40% av befolkningen slagit rot, är möjligheterna för både god luftkvalitet och tillräcklig avfallshantering begränsade. 58% av allt som slängs idag i Chile är organiskt avfall och tuffa ekonomiska förutsättningar hos kommunerna, gör att förändringen mot ett cirkulärt materialflöde går långsamt. Samtidigt står landet inför den globala utmaningen att minska växthusgasutsläppen till hållbara nivåer.

I denna studie, undersöks därför flöden av organiska avfall i kommuner som tillhör den Metropoliska Regionen i Chile, för att beräkna biogaspotentialen och hur dess bidrag till minskad klimatpåverkan. Metoderna som används för datainsamling är litteratur- och intervjustudie, och data hanteras genom fallstudier. Resultatet av biogaspotentialen presenteras i Nm^3 och GWh per år. Näringsinnehållet i flödena undersöks, likaså hur väl materialet passar som substrat till biogasproduktion genom syrefri nedbrytning, och dess bidrag till biogasens energiinnehåll. Typvärden för biogaspotentialen på kommunal och regional skala tas fram och sätts i kontext genom tidigare presenterade data från Chiles avfalls- och energimarknad.

Två chilenska kommuner (El Monte och Providencia) och deras rena flöden av organiskt avfall undersöktes, följt av en framtagen fiktiv genomsnittlig kommun, som användes för att representera kommunala typvärden. Resultatet från studien visade att det finns en stor variation i form av mängd och substrattyp hos flödena i de olika kommunerna. En typisk kommun i den Metropoliska Regionen i Chile har en biogaspotential på 86 GWh per år och hela regionen en potential på 4 500 GWh per år. Den regionala biogaspotentialen hade räckt till att driva 67% av alla bussar i kollektivtrafik i regionen, alternativt 78% av regionens lastbilsflotta. Om avfallet i regionen hade omvandlats till biogas som använts till att driva fordon som idag går på fossilt bränsle hade potentialen även kunnat bidra till en minskning av 2 miljoner ton CO_2-ekv växthusgasutsläpp per år, motsvarande 2% av de nationella nivåerna.

I studiens slutsats konstaterades att syrefri nedbrytning av organiskt avfall i Chile skulle vara ett steg i rätt riktning inom flera av de nationella riktlinjerna. Fortsatta studier av marknad, processteknik och substratmix rekommenderas för att sätta en optimal riktkurs för en framtida implementering.

Nyckelord

Chile, “Metropoliska Regionen”, Santiago, “El Monte”, Providencia, avfall, organisk*, nedbrytbar* avfallshantering, industriavfall, kommun*, skatt*, lag*, energi, elektricitet, “förnyelsebar energi”, biogas, “syrefri nedbrytning”, bränsle, kraft, miljö, återvinn*, rural*

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LUND UNIVERSITY
Department of Technology and Society
Environmental and Energy Systems Studies
Box 118
SE - 221 00 Lund, Sweden
Telephone: int+46 46-222 00 00
Telefax: int+46 46-222 86 44

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Filippa Bengtsson

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Abstract

In the Metropolitan Region in Chile the population is growing as the inhabitants are relocating towards the capital of Santiago de Chile. The capital, located in a valley, is now home to over 40% of the population, and faces challenges with sufficient air-quality and waste disposal. 58% of all waste in Chile today is of organic matter, and with economical limitations in the municipalities, change towards a circular economy happens slowly. At the same time the country faces the global challenge of lowering greenhouse gas emissions to sustainable levels.

This study thus aims to investigate flows of organic waste in municipalities of the Metropolitan Region in Chile, to estimate the biogas potential and its possible contribution to lowering the national greenhouse gas emission levels. The methods that are used for data collection are literature and interview studies, and the data is further processed through case studies. The resulting biogas potential is presented in Nm^3 and GWh per year. The substrate composition in the flows is investigated and discussed, as well as the convertibility of the substrate in anaerobic digestion and its contribution to the energy content of the biogas. Average values of the biogas potential on municipal and regional scale are calculated for and are put to context through presented data from the Chilean waste and energy market.

Two Chilean municipalities (El Monte and Providencia) and their pure flows of organic waste were studied, as well as an average fictive municipality that was created and used to represent typical municipal values in the region. The result of the study showed that there is variation in terms of amount as well as substrate type in the municipal waste flows. The average municipality in the Metropolitan Region in Chile had a biogas potential of 86 GWh per year, and the region 4 500 GWh per year. The regional biogas potential could be enough to run 67% of the regional buses in public transport, or 78% of the trucks in the region. The biogas potential could also contribute to lowering Chile's total annual greenhouse gas emissions with 2 million tons of CO_2-eq, corresponding to 2%.

The conclusion of the study shows that anaerobic digestion of organic waste in Chile would be a step in the right direction of several of the national guidelines. Additional studies of the market, process technology availability and substrate mixture models are recommended, to optimize the direction of a future implementation.

Keywords

Chile, "Metropolitan Region", Santiago, "El Monte", Providencia, waste, organic, biodegradable "waste management", "industrial waste", municipal*, tax*, law*, energy, electricity, "renewable energy", biogas, "anaerobic digestion", fuel, power, environment*, recycl*, rurality

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Preface

This master thesis has been written as a part of the educational curriculum to obtain the title Environmental Engineer from the Faculty of Technology at Lund University, Sweden.

The thesis would not have been feasible without the contribution from the representatives of the Department of Environment in El Monte (Don Eduardo and Carolina) and in Providencia (Paloma, Christian and Maria). Without your dedication and time set aside to help me with the data I needed, performing the study as it was done would not have been possible.

I would also like to thank Mariela Pino from RedBioLAC for the great support during my study and for helping me reach out to the correct people, and Arturio Arias for making time to give me a full tour of the waste treatment facility at KDM Empresas.

Thank you to all other representatives of Chilean ministries, food producers, companies, and NGOs that have taken their time to help me with information and data for the study, without you the information search would have been much harder, and not as exciting as it was.

My supervisors have also been of great help during my study, and I would like to thank both prof. Pål Börjesson at Lund University and Ronny Arnberg at IVL Swedish Environmental Research Institute for being flexible with calling times due to the time difference, and for checking in on my progress on a regular basis. Thank you as well to prof. Lovisa Björnsson at Lund University for showing interest in my work and for being my examiner and to Anders Hjort at IVL for helping me with specific information regarding biogas calculations.

Thank you as well to the Crafoord Foundation and Margit Stiernswärd’s Fund for Environmental Research that both provided me with grants that covered my 3-months field study in Chile.

Lastly, I would like to thank my family and friends that always support me. My wild ideas, such as traveling alone to the other side of earth to do my thesis, do not even seem to surprise you anymore. Thank you for always being there for me, for helping me through tricky situations, and for celebrating victories together. Without your support I could not have been as courageous.

Lund, 2nd of June 2021

Filippa Bengtsson

Table of content

1 Introduction

This chapter will present a short introduction to this master thesis as well as the goal, research questions and scope of the study. The information aims to give the reader understanding of why this study has been made, and towards what questions are to be answered throughout the report. Lastly, the disposition of this thesis is presented.

Climate change is a global issue but nevertheless requires national action to not surpass the irreversible point of global warming. Climate change also affect nations differently. A report from the United Nations (Bárcena et al 2015) predicts that, the effects from climate change may cause severe problems in countries where agriculture is an important part of the national economy. According to the United Nations Development Programme's information on nations' climate change adaption (UNDP 2021) a new council was introduced in Chile in 2008 under the Agricultural Ministry, to handle specific issues related to climate change. Since then, extensive studies on the theme have been conducted by the council which has led to radical changes in the national Chilean policies to lead the nation towards a fossil free future.

Agricultural nations also produce large amounts of organic residues. According to a report from the Food and Agriculture Organization of the United Nations (Gustavsson et al 2011), Latin America as a region has a high organic waste fraction, and in fruit and vegetable production about 55% ends up as waste whereof 20% is lost already in the agricultural phase of production. Mixed municipal waste in Chile also holds a high fraction of organic waste. Statistics shows that 58% of municipal waste is organic matter, which lays as foundation for the current strategy for recovery of organic residues that was finalized no later than March 2021, by the Chilean government (Ministerio de Medio Ambiente 2020, Pino 2021). The strategy presents a 20-year plan with the main directive proposed in the report being the encouragement of implementation of composts in private domiciles and communal areas. This may seem like a small step but bearing in mind that 99% of the country's organic waste today ends up in landfills, the consciousness of valuing organic residues is slowly increasing in the nation.

To take advantage of not only the nutrients in the organic residues, but also the energy, anaerobic digestion of the organic waste could be an alternative. Anaerobic digestion is a natural process that generates biogas, which is a high-energy gas that can be used in several energy demanding segments in society, such as transportation, heating, or electricity generation. The motive of this master thesis is therefore to investigate the biogas potential that could be generated from organic waste in municipalities of the Metropolitan Region of Santiago de Chile, to see what impact the potential may have in the energy demanding segments of the region. Moreover, the potential decrease of climate impact derived from implementing anaerobic digestion of the organic waste found will be explored. The investigation will both cover easily accessible waste flows of pure or nearly pure organic matter, the so called "lowest hanging fruits" of biogas production, as well as less accessible organic waste found in for example mixed municipal waste, to broaden the perspective of future possibilities for anaerobic digestion from increased source separation in the country.

The master thesis is part of the education at the Faculty of Engineering at Lund University, and will lay as foundation for the title as Environmental Engineer. The work has been supervised by the IVL Swedish Environmental Research Institute, which is an institute with long history of environmental projects, both in Chile and internationally.

1.1 Goal and research questions

The goal of this thesis is to investigate the potential biogas expressed as volume (Nm^3) and energy (GWh) that could be generated on a yearly basis from organic waste in municipalities in the Metropolitan Region of Santiago de Chile, to see what impact making use of the potential could have on energy demanding segments of the region and on Chile's greenhouse gas emissions. To accomplish the goal, the following research questions are to be answered.

1) How is organic waste handled in Chile today, and; what energy demanding segments in the Metropolitan Region exist where biogas could be used as an alternative energy resource?
2) Which are the greater sources on municipal level in the Metropolitan Region that generate organic waste; how much do the sources generate on a yearly basis, and; what type of organic matter do the sources consist of?
3) What is the potential amount of biogas and energy that could be generated from organic waste on municipal level and in the Metropolitan Region as a whole?
4) To what extent could converting organic waste into biogas in the Metropolitan Region contribute to lower Chile's greenhouse gas emissions?

1.2 Scope

The study aims to investigate different levels of implementation, by studying both specific data from sources that generate easily separable organic waste, so called "pure flows", as well as general data from mixed waste containing high organic fractions. The pure flows could represent the potential from the "lowest hanging fruit" of biogas production and by incorporating mixed flow with high organic fraction, a futuristic view including increased source separation of the total biogas potential is obtained. The geographical scope of the study is limited to the Metropolitan Region of Santiago de Chile and the data for the pure flows is limited to the municipalities that are selected for the study.

1.3 Disposition

The next chapter of the study will give a short overview of Chile and the studied area of the Metropolitan Region of Santiago de Chile. Chapter three will explain the method used for the investigation, followed by a descriptive chapter of biogas production systems, which is needed to understand the calculations of biogas potential and energy conversion performed.

The findings of the study are thereafter presented, divided into two chapters: one of waste handling and energy demanding segments in Chile and one of biogas substrate assessment of the studied municipalities and region. These two chapters lay the ground for the case studies performed, which are presented in the results. The findings of the thesis are thereafter discussed before closing the loop by answering the research questions in the conclusion. At the very end references and appendices referred to in the text are found.

2 Background

This chapter will present the socio-economic and geographical conditions of Chile and aims to provide the reader sufficient knowledge on the prerequisites of Chile as a nation, as well as an overview of selected municipalities in the Metropolitan Region of Santiago de Chile, to understand the basis of the study performed.

2.1 The Republic of Chile

Chile is a country that stretches 4 270 km along the south-west coast of South America, from Antarctica in the south, to the Atacama Desert in the north. In the west, the border is made up by the Pacific Ocean while the east is cut off by the massive mountain range of the Andes. Due to the unique narrow shape of the country, as well as the height differences and valleys formed between the ocean and the mountains, the climate varies dramatically, often also within the same region (ODEPA 2019).

The nation is divided into 16 regions. The capital Santiago de Chile is found in centre of the land, in the Metropolitan Region (Spanish*: Región Metropolitana de Santiago de Chile*), also referred to shortly as *RM*. The region is an area of 15 400 km^2 (Gobierno Regional Metropolitano de Santiago 2017) and can be seen in the map of Chile in Figure 1, marked with the denomination *RM*. According to the National Institute of Statistics (INE 2019a), Chile is home to 19 million people of which 88.4% live in urban areas, and the number is increasing. 8 million people, which corresponds to 42% of the population, live in RM and projections suggest that RM will have almost 9 million inhabitants by the year 2035. Worth noting is that RM only accounts for 2% of the geographical surface of the country, which makes the rising urbanisation to the capital problematic.

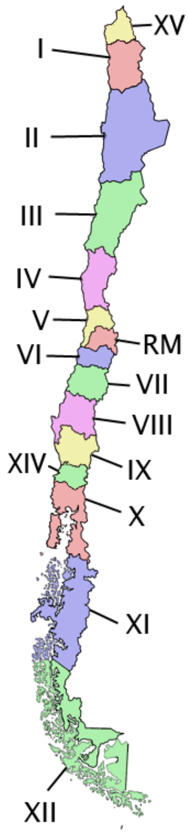

Figure 1. Map over Chile and its regions.[1]

2.2 National and regional conditions

Due to its shape and topography, Chile is home to several climates. The Metropolitan Region and the city of Santiago de Chile, (a panorama of the city seen in Figure 2) covers both parts that are warm and rainy with inland influence, as well as cold temperate with winter rains (ODEPA 2019). From a personal experience, the author claims that it seldom rains in Santiago during summer. Locals confirm this (Miranda and Mendez 2021, Pino 2021), but also point out that the ongoing climate change has made the climate in the region even drier during later years.

[1] Nuevo mapa de las 15 regiones administrativas de Chile (new map of the 15 administrative regions of Chile) by thejourney1972 (South America addicted) is licensed under CC BY 2.0. To view a copy of this license, visit https://creativecommons.org/licenses/by/2.0/

Figure 2. Panorama of Santiago de Chile (Source: Author).

The reasons behind the varying climates are several. A large surface of the country, including RM, is located in valleys between two mountain ranges; *the Chilean Coast Range* and *The Andes*, which makes climate significantly different from locations closer to the coast. The topographic formation of the landscape in combination with specific climate conditions also cause Santiago de Chile to suffer from bad air quality, due to so called "thermal inversion" (Ministerio del Medio Ambiente 2016). The phenomenon is explained in Figure 3 and the text below.

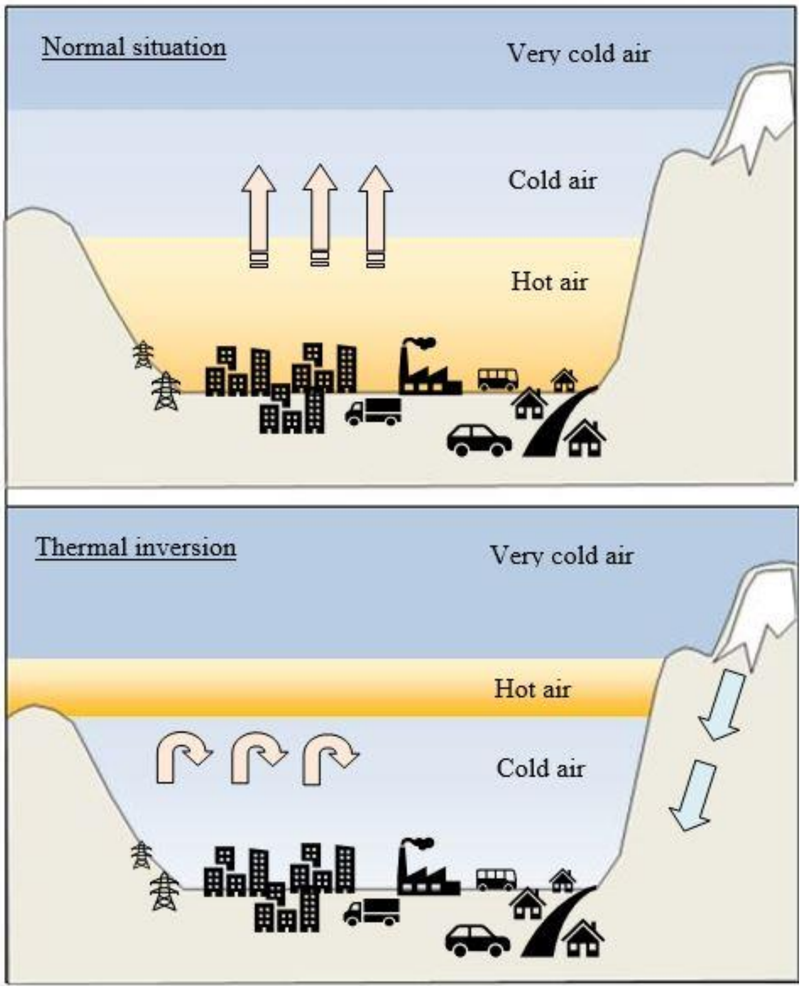

Figure 3. The phenomenon of thermal inversion that is common in Santiago de Chile (Source: Author).

Hot air tends to rise, and on a normal basis this is what happens when the sun heats up the surface of the Earth. The air moves upwards and while so, it cools down further away from the surface. This can be seen in the first picture in Figure 3, as the "normal" scenario. In the second picture, hot air has formed a layer that stretches between the mountain ranges, which "traps" the cold air underneath, forcing it to recirculate (Briney 2020). Thermal inversion is more common in wintertime in Santiago de Chile, when the cool air comes submerge from the mountain ranges during night and pushes the hot air upwards. The situation can cause extreme weather, such as freezing rain, thunderstorms, and tornadoes. Thermal inversion is also worsening a common environmental problem – air quality. When the air closest to the surface no longer can rise out of the valley because of the hot-air tap, the air is trapped, and so are the contaminants.

There are several ways of measuring air quality, for example abundance of "particular matter", or PM for short. PM is expressed in size fractions depending on the maximum diameter of the particles that are measured, for example 10 µm and 2.5 µm which are commonly written as PM_{10} and $PM_{2.5}$. Another measurement can be emissions of compounds that are causing harm to living beings or nature, such as sulphur oxides (SO_x) or nitrogen oxides (NO_x). The latest measurements for $PM_{2.5}$ in Chile took place in 2018 where 24 out of 38 monitoring stations showed a higher value than the set standard of 20 µg/m^3 (Sinia 2019). Measurements for PM_{10} showed a slightly lower outcome, with 19 of the stations monitoring values over the set standard of 50 µ/m^3.

Looking at the levels of NO_x, the RM has the highest emissions amongst the regions in Chile, as seen in Figure 4 (Sinia 2019). The high levels are strongly connected to the transportation sector, which contributes to about 80% of the NO_x emissions in the region. RM also has high values of particular matter but is surpassed in the latest $PM_{2.5}$ measurements by several regions in the south where the climate is colder, and most houses still burn wood for heating. The SO_x emissions in RM compared to other regions are low, since metal casting in connection to mining activities in the north and centre of the country release massive amounts of sulphur oxides.

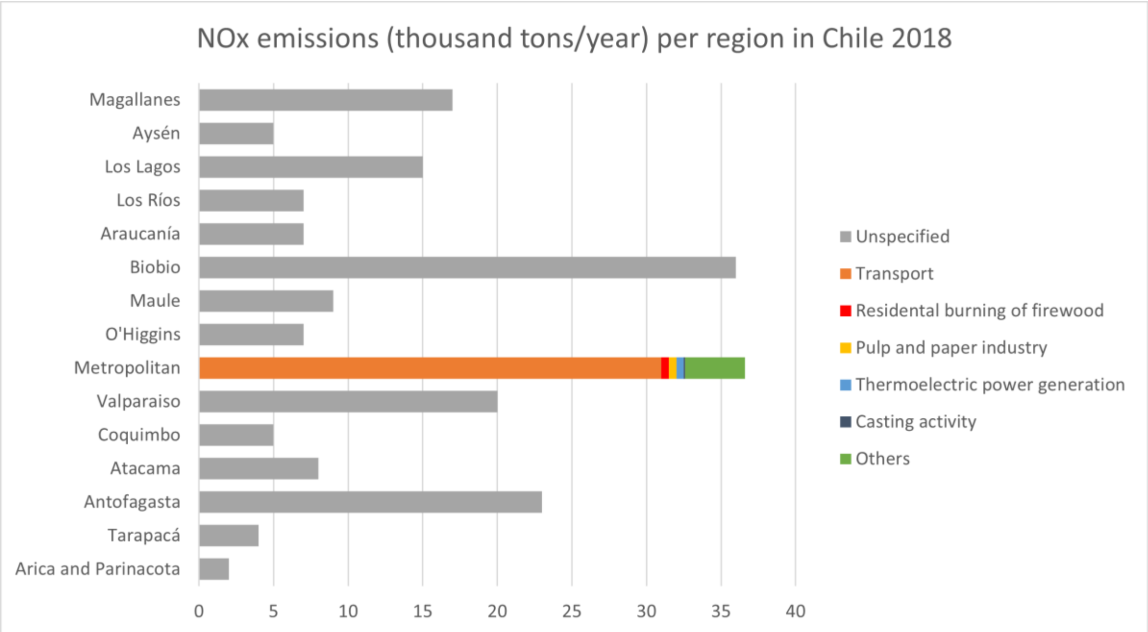

Figure 4. NOx emissions per region in Chile 2018 in thousand tons/year. Diagram constructed by author. (Sinia 2019).

2.3 Selected municipalities for the study

RM is divided into six provinces and 52 municipalities (Gobierno Regional Metropolitano de Santiago 2017). In this study, as seen in Figure 5, the municipality of El Monte marked with red background, located in the province of Talagante, and the municipality Providencia marked with turquoise background, in the province of Santiago, will be studied further. The rational for selecting these two municipalities is further explained in Chapter 3.

Figure 5. The Metropolitan Region in Chile[2]. The two selected municipalities are marked, El Monte with red background and Providencia with turquoise background.

2.3.1 El Monte

El Monte is slightly over an hour's bus ride from the busy city centre of Santiago de Chile towards the south-west. The road that leads to the centre of El Monte follows the Mapocho River through the valley named Maipú, before finally crossing the water to reach the village of El Monte. The municipality is located about 47 km from the centre of the capital (Municipalidad de El Monte 2019), and although it being a part of the Metropolitan Region,

[2] Map from © OpenStreetMap contributors, used via the Open Database License under CC BY-SA 2.0 https://www.openstreetmap.org/copyright

the sensation of arriving to the countryside far away from the hectic city when arriving, is inevitable.

The north-west of the municipality is limited by small mountains of which the village got is name (El Monte translates to The Mountain). In the south-east the Mapocho River makes up the border towards the neighbouring municipalities of Talagante and Isla de Maipu. The location between the mountain and the river makes El Monte ideal for farming, with the river providing water and the mountain providing refuge from the seasonally overwhelming sun. Lately, climate change in combination with insufficient waste handling has resulted in less water in the river, as well as challenges of plastic pollution (Miranda and Mendez 2021).

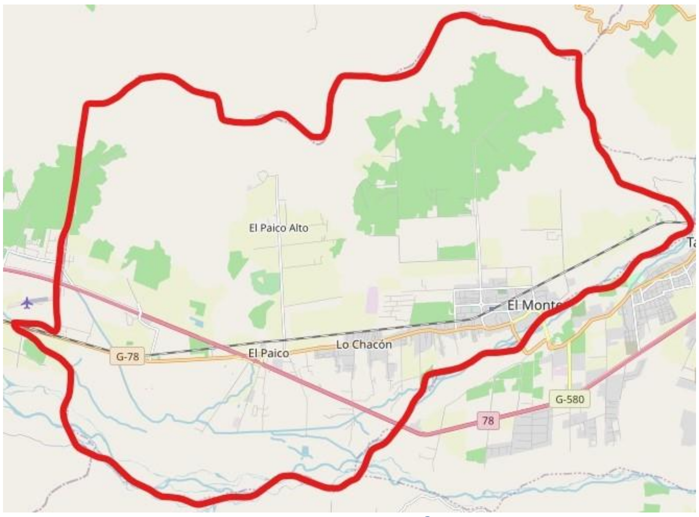

Figure 6.The municipality of El Monte[3]. Edited by the author.

The village and its surrounding area that make up the municipality (seen in Figure 6) has a total area of 118 km^2 and is populated by almost 36 000 people (Municipalidad de El Monte 2019). El Monte is classified as rural on a scale 3 out of 4 according to the Ministry of Social Development (SEREMI 2019). According to the same report, 16.4 % of the population in El Monte live in rural conditions and 17% of the population is working within the primary sector (fishing, agriculture, mining etc.).

Although the relatively small population, there is high interest from the Department of Environment of the Municipality El Monte to make a difference for future generations. In the beginning of 2021, a recycling station (Spanish: *Punto Limpio*) was put up in the centre of the village, enabling the inhabitants to sort out valuable materials such as glass, paper, and plastics from their waste (Miranda and Mendez 2021), see Figure 7. The recycling station is one out of 30 in total in RM as is part of an initiative by the Ministry of Environment named Santiago Recycles (Spanish: *Santiago Recicla*)(Canales 2021).

[3] Map from © OpenStreetMap contributors, used via the Open Database License under CC BY-SA 2.0 https://www.openstreetmap.org/copyright

Figure 7. Mariela Pino from RedBioLAC together with Eduardo Miranda and Carolina Mendez from the Department of Environment of the Municipality of El Monte, in front of the newly installed recycling station in El Monte. (Source: Author).

The effort of engaging the villagers in waste handling and is slowly paying off and today it is estimated that 95% of all waste generated in the municipality is collected (Miranda and Mendez 2021), comparable to the national average of 80% (Arias 2021). The governance of the municipality is also currently investigating new alternatives of energy sources, since they believe that the change to sustainable solutions is urgent. Some of the other ongoing projects in the municipality are a community compost and solar panels (Miranda and Mendez 2021).

2.3.2 Providencia

The relatively small geographic area of 14 km^2 that makes up the municipality of Providencia is home to about 150 000 people (Valenzuela Hernándes et al 2021). The buildings in the municipality are almost exclusively apartment complexes, stores, and offices, as seen in the distance in Figure 8.

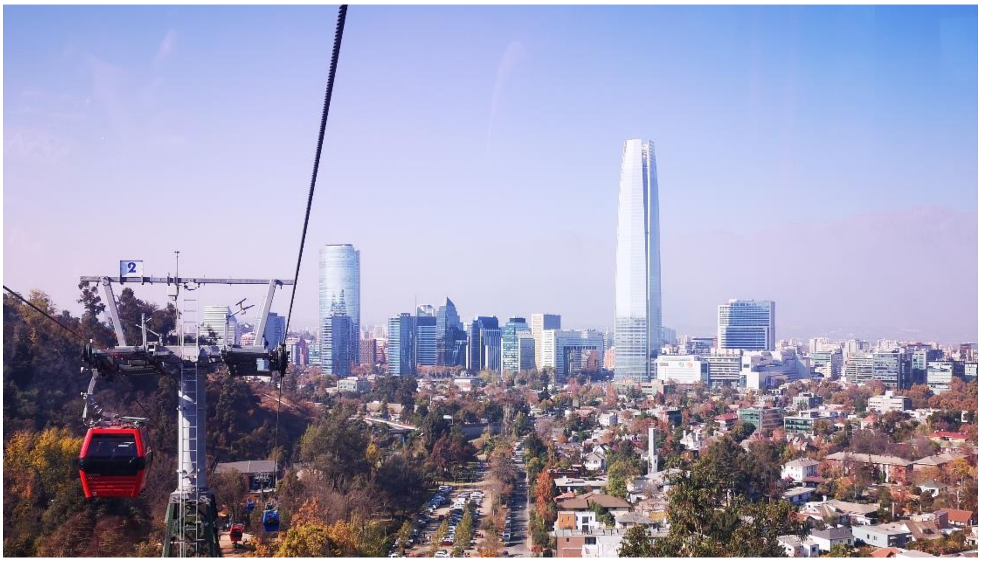

Figure 8. View over Providencia and the Gran Torre Santiago, the tallest building in South America. (Source: Author)

Providencia is classified as urban and on the lowest scale of rurality with 0% of the population living under rural conditions (SEREMI 2019). The municipality is located in the centre of the province of Santiago, and a street view can be seen in Figure 9. The socioeconomic and health condition of the population in the municipality is ranked as third best on a national level (OCHISAP 2011). Due to the high density of people, the small municipality also has a division of 16 neighbourhoods where each neighbourhood has their own board that work together with the inhabitants as a support in the community (Municipalidad de Providencia 2021).

Figure 9. The municipality of Providencia[4]. Edited by the author.

There is also governance over the entire municipality, where larger projects that includes all neighbourhoods are conducted. At the Department of Environment in the Municipality of Providencia (Municipalidad de Providencia 2021) there are ongoing projects on recycling, minimizing of single-use plastics, energy and water usage, and environmental education in all levels of society. Regarding recycling of organic waste, the first projects were initiated in 2017. Since then, the interest of the topic has grown, especially by the usage of compost to recycle the nutritional value of the organic material. Until now 3250 kits for recycling organic materials have been distributed in the municipality, which includes both separation vase and a small-scale compost or vermicompost. During 2021, one thousand additional kits will be distributed.

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3 Method

In this chapter the methodologies of the study will be presented, to explain how the information presented in this investigation was obtained and further processed in various calculations generating final results. First, an overview of the workflow is shown, followed by a description of the choice of methods and explanations of how the methods were interpreted and used in the study.

The investigation was performed through various methods. The first research question regarding Chile's waste handling system and RM's energy demanding segments, as well as the second research question that investigated possible biogas substrates from organic waste in the selected municipalities, were approached by performing both a literature study and an interview study.

To answer research questions 3 and 4, three case studies were made. Two contained the resulting biogas potential derived from the findings from the biogas substrate assessment of the selected municipalities of El Monte and Providencia, respectively. In the third case study the data from both specific and general sources was interpreted to create a fictive, typical, municipality, that laid the basis of the calculations for biogas and energy potential on both a general municipal level and on regional scale. The resulting biogas potential found in the case studies was thereafter put into context by using the information found in the waste handling and energy demand research performed.

Below, a schematic overview of the workflow and methods used can be seen in Figure 10. The methods are highlighted with green background and are to be explained in this chapter.

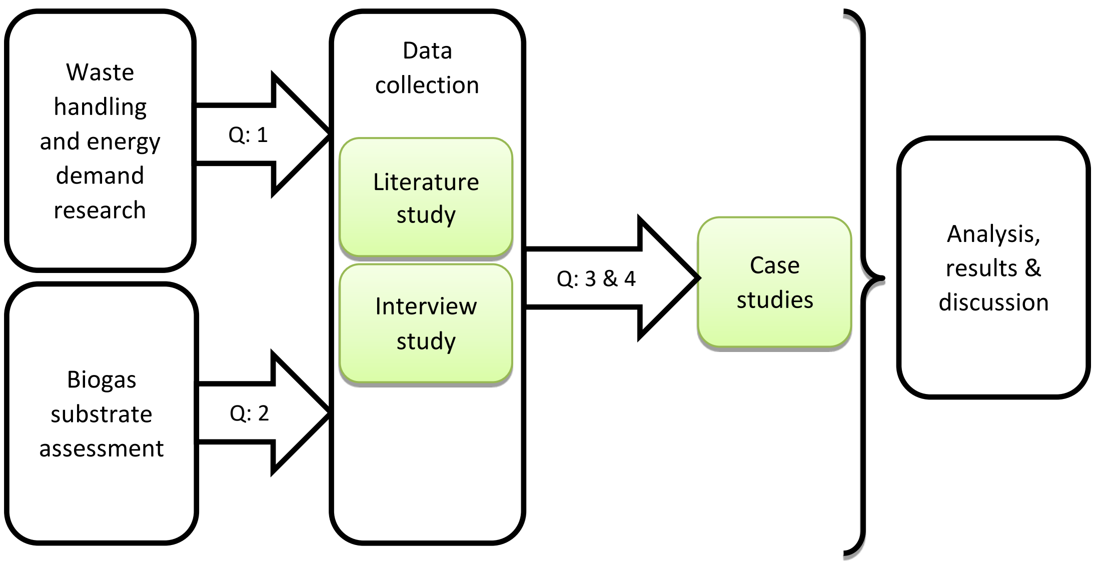

Figure 10. Flow chart of the work process of the study. The research questions can be seen in the arrows, pointing at the methods used to answer them. The methods are highlighted with green background. Diagram made by author.

The information for the waste handling and energy demand research held the following priority order:

1) Information from official statistics and reports offered by Chilean ministries.
2) Information obtained through interviews with relevant actors.
3) Information from scientific papers and official websites.

For the biogas substrate assessment, the priority order was as followed:

1) Data obtained directly from producers of organic waste.
2) Statistics from official databases in Chile or Sweden.
3) Data retrieved from interviews with relevant actors.

3.1 Literature study

A literature study was used to both find relevant information in for the research on waste handling and the energy demanding segments of Chile and RM, as well as finding general data for the biogas substrate assessment. The information regarding waste handling and energy was found mainly in official documents on strategies and statistics from ministries of Chile, but also to some extent in scientific studies, principally from Chilean universities, searched for via LUBSearch and Google Scholar. Information was also found in studies suggested directly from involved actors and supervisors. The data for the biogas substrate assessment that was found through literature study was mostly general data, for example organic waste from open-air markets in all of RM. The waste data was gathered principally through official data bases suggested by involved actors, such as the official data collection of municipal and industrial waste found in SINADER (the national system of waste declaration in Chile). Some data was also retrieved from spreadsheets of statistics and prognoses directly from the involved actors, for example from KDM Empresas and the Ministry of Environment in Chile. The literature study was also used to complement the data retrieved in via the interview study, with for example geographical data, to be able to perform the case study of the fictive, typical municipality, which is explained later.

The key words and databases used in the literature study can be seen in Table 1.

Table 1. Key words and databases used in the literature study. The key words were also translated to Swedish and Spanish and used in the information search.

Key words	Chile, “Metropolitan Region”, Santiago, “El Monte”, Providencia, waste, organic, biodegradable “waste management”, “industrial waste”, municipal*, tax*, law*, energy, electricity, “renewable energy”, biogas, “anaerobic digestion”, fuel, power, environment*, recycl*, rurality
Databases	LUBSearch (university licence enables access to other data bases, for example ScienceDirect), Google Scholar, SINADER (Chile), INE (Chile)

3.2 Interview study

According to a reference guide published at Uppsala University (Hedin and Martin 2011), a qualitative interview study can be used when the answers it is difficult to know beforehand what the outcome of the study will show. Usually, the number of interviewees is low, and the process of research is inductive, meaning that the information found is interpreted to form the conclusion, instead of it aiming to prove a hypothesis (Hedin and Martin 2011).

When performing an interview study, it is of importance to consider ethical aspects of the process. The European Federation of Academies of Sciences and Humanities, or for short ALLEA, published a code of conduct for research integrity in 2017 (ALLEA 2017). The code of conduct highlights four ethical principles, of which each researcher should follow when consider when performing a study.

- **Reliability** – to ensure that the quality of research remains high throughout all the research process.
- **Honesty** – to be transparent and fair in all stages of data treatment in an unbiased way.
- **Respect** – to be considerate of all people involved in the process, as well as surrounding environments.
- **Accountability** – to take responsibility for the research from idea to publication and for its wider impact.

The principles should be considered during all the study, but when involving external actors, their importance becomes even greater.

For this master thesis, a qualitative interview study involving external actors was used as the primary method of the data collection to the biogas substrate assessment, as well as a complementary method in the research of national waste handling and energy demanding segments in RM. During the interview study, the code of conduct presented by ALLEA (ALLEA 2017) was followed carefully.

All actors contacted for interviews can be seen in Appendix 1, as well as the people that accepted an interview, their position and contribution to the study. The interviews were held in person, through digital platforms or via email, and followed a structure of predetermined questions that can be found in Appendix 1. The interviews were semi-structural, which means that if the interviewee had more information on a certain topic, it was accepted that some questions were discussed more thoroughly, and follow-up questions were often asked to keep the interview more conversation-like (Hedin and Martin 2011). This also led to that some of the interviews generated more information than only the answers to the predetermined questions.

The selection of actors contacted was based primarily on already established contacts, principally by suggestion from the supervisor at IVL, later by suggestions from interviewed actors. Webinars in Chile on the theme was also attended, were the author rose the question if there was interest among the participants in the study and if they had connection with relevant actors, to broaden the contact network. Regarding the interviews with producers in El Monte, the representatives of the municipality were of much help by establishing contact as well as lending their time and vehicle to interview the producers in person.

Before each interview, the purpose of the study was presented by the author to the interviewee, followed by information of how their answers during the interview would contribute to the study in the master thesis. Most interviews were recorded and transcribed, after verbal agreement from the person interviewed. The interviewee also had the possibility to remain anonymous if requested. Almost all interviewed were held in Spanish, and the questions seen in Appendix 1, as well as their contribution to the study, have been translated to English by the author.

In total, contact was established with three companies, one governmental programme, two ministries, four NGOs, five municipalities and four local food producers generating organic waste. All actors are present in Chile.

3.2.1 Selection of municipalities

The primary method of the data collection was through the interview study and establishing contact with relevant actors was therefore crucial to obtain the data directly from the source. The principal selection criteria of which municipalities to study was therefore based on personal connection via supervisors or interviewed actors. To gain sufficient information to draw conclusions on a larger scale, the author anticipated to study more than one municipality, with the aim that the chosen municipalities would have a diversity in terms of rurality as well as number of inhabitants. Lastly, it was important to obtain data from different sectors and industries within the municipality to have enough data to draw conclusions on municipal level, as well as on a regional level.

The choice of the municipalities studied was therefore made having the following order of priority in mind:

1) Connections and contacts – to get a reliable basis of data.
2) Variety of number of inhabitants and rurality – to be able to draw more accurate conclusions on a regional scale.
3) Variety of organic source type – to get a broader data range and variation in biogas substrate that can be analysed and discussed.

In total, seven municipalities were contacted, five of them replied, and two provided enough data (El Monte and Providencia) to be considered enough to be selected for the study.

3.3 Case studies

To answer research question 3 and 4, case studies using the data found in the literature- and interview study were performed. First, the data of pure organic waste flows in the selected municipalities El Monte and Providencia were studied in two separate case studies. The data for El Monte was retrieved directly from few but specific sources, which made the author take the decision on amplifying the findings to include other sources of similar type in the municipality, to calculate the potential all pure substrate flows could generate on a municipal level. The case study for Providencia was not amplified due to the general and amplified nature of the data already collected. A third case study was then made, where a fictive municipality was created and designed from average data, to represent an average municipality in the region and to be able to draw conclusions from the results on a larger scale. All calculations and motivations to reach the data for the fictive municipality can be found in Appendix 3.

The basis of normalization of the data to fit the fictive municipality was done by the taking into consideration:

- Geographic area
- Rurality
- Number of inhabitants
- Number of households

3.4 Calculations

Calculations and estimations were made in several stages to reach the results of this study. Some of the calculations were made already in the presentation of the data from the sources, to present the data with consistency to the reader, in terms of tons or organic waste per year. In the cases where the data presented has been obtained through calculations, this is mentioned under the section of the source presentation, and their original data is found in Appendix 2. Some examples are:

- The data from the seedbed farm in El Monte, Semillero Avenida San Miguel, where all substrates were given in cubic meters. The conversion from cubic meters to kilograms was performed using the data found on the density of the substrate, as seen in Appendix 2.
- The water treatment plant in El Monte, Tratamiento local Lo Chacon had no specific data about the waste, only the number of households which were connected. The conversion to energy and biogas potential was made using data of Swedish conditions from Svenskt Vatten (Finnson and Lind 2020).

3.4.1 Model of biogas and energy potential

To perform the calculations leading to the biogas and energy potentials of the studied municipalities, as well as the fictive municipality, a model was built using Microsoft Excel. The model used data regarding substrate and corresponding biogas yield and methane content from several information sources (Avfall Sverige 2009, Chamy and Vivanco 2007, Hjort 2021, Svenskt Gastekniskt Center 2012). Both the model and the organic substrates with corresponding yield are found in Appendix 4.

The calculation to reach the biogas potential was made depending on substrate type and was performed in the following way:

$$Biogas\ potential_{source} = \sum Biogas\ generation_{substrate}$$
$$= \sum \left(Wet\ weight_{substrate} * \frac{TS_{substrate}}{wet\ weight_{substrate}} * \frac{Nm^3\ biogas}{TS_{substrate}}\right)$$

were TS stands for the *Total Solids*, or dry content, as explained in the next chapter and Nm^3 is the normal volume in cubic meters for dry gases at 0°C and 1 atm. The methane potential from the biogas was then calculated, also depending on substrate type:

$$Methane\ potential = \sum (Methane\ content_{substrate} * Biogas\ generation_{substrate})$$

The energy content of pure methane was calculated from the lower calorific value of methane combined with the density of methane at 0°C and 1 atm.

$$Energy\ content_{methane} = 13.9 \frac{kWh}{kg} * 0.716 \frac{kg}{Nm^3} = 9.97 \frac{kWh}{Nm^3}$$

Thereafter, the energy potential could be calculated, by combining the equations above.

$$Energy\ potential = Methane\ potential * Energy\ content_{methane}$$

3.4.2 Assumptions and uncertainties

When performing some of the calculations, assumptions had to be made. The model of biogas and energy potential does for example assume that all the substrates could be used for generation of biogas, and that there will be no complications in terms of mixing, microbial conditions, leakages of methane or similar. This means that the value obtained is highly theoretical and that to perform calculations that would correspond better to a real scenario, experimental tests should be conducted and studied, as well as large-scale production in pilot plants, etc. Problems that can be faced depending on specific substrates and mixtures are discussed further in the next chapter.

The model is dependent of substrate type as well as yearly substrate flow expressed in tons wet weight. This means that depending on how the data of the substrate flow is interpreted and categorised to correspond a substrate in the model can lead to varying results in the biogas and energy potential. During the study, there were several examples where data was difficult to interpret. Some of them were:

- Since organic waste is separated in Chile, it is difficult to know the exact fraction in of organic material in the mixed flows. For example, supermarkets in Chile usually have large sections with fruits and vegetables, as well as meat and cheese in the store. However, since the waste that is generated from these high-fraction organic sections is mixed with other waste, the data from SINADER regarding the waste from supermarket is categorised as “Mixed municipal waste”, with no indication on the organic fraction. The author reached out to specialized NGOs in Chile but did not find any regional, nor national, data on the waste composition from supermarkets. The estimated organic fraction from supermarket waste used was instead found in a scientific study regarding composition of supermarket waste in Ecuador which was assumed to be of similar character in Chile.
- Data from the slaughterhouse of Ariztía was also obtained through SINADER, since the company could not share their internal data regarding waste and costs due to company policy. The numbers that were found did not specify the composition more than it being slaughterhouse waste, and the author had to estimate of what type the slaughterhouse waste could be. The estimation was it being of gastrointestinal type,

but if the waste flows largely consist of for example bones, feathers, or blood, it is possible that the results would have been different.

- In the subchapter 6.3 presenting general data, some assumptions regarding municipal waste had to be done. As seen in Appendix 2, the data sheet from KDM Empresas (Arias 2021) projected the quantity of municipal waste for 2021. The data sheet also presented a study on material fractions per municipality showing that 58% of waste municipal waste is organic material. The estimation made by the author was that the quantity of waste projected, as well as the fraction of the municipal waste was true and could be classified as *Mixed food waste (domestic)* in the model.

4 Description of biogas production systems

This chapter will aim to provide sufficient technical knowledge for the reader to understand anaerobic digestion and the calculations of biogas potential depending on substrate composition and required operating conditions. It will also point out challenges that are faced within biogas production systems, and what parameters are important bearing in mind when designing a bioreactor to perform anaerobic digestion.

Biogas is a mixture of gaseous compounds, mainly methane and carbon dioxide, and is formed by decomposition of organic material during anaerobic conditions (Svenskt Gastekniskt Center 2012). The process is a result of collaboration between different microorganisms and the yield of the biogas production depends on the proximity of optimal conditions for the microorganisms to thrive.

The process can be divided into several steps that can be seen in Figure 11.

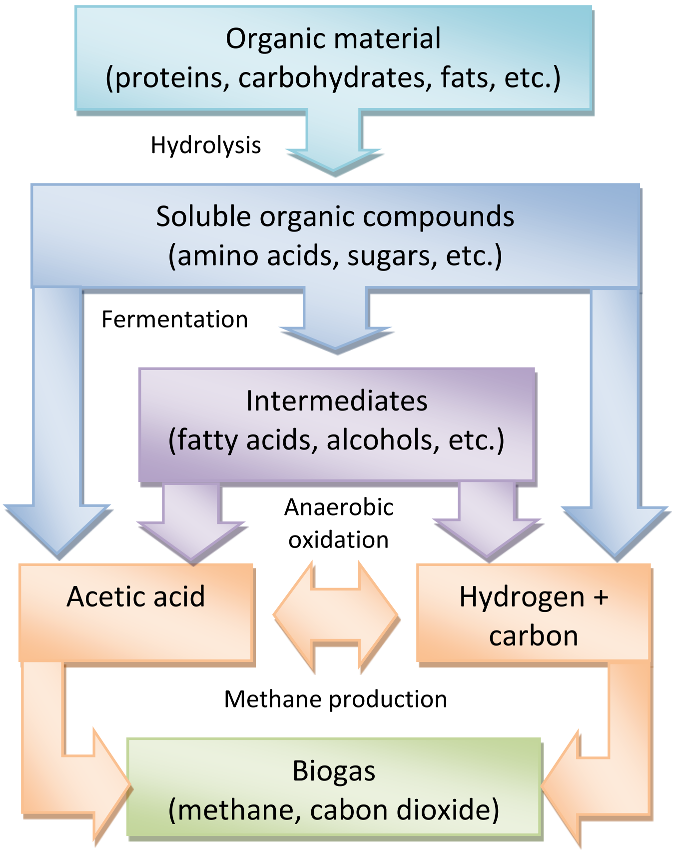

Figure 11. The process of anaerobic digestion. Diagram constructed by the author. (Svenskt Gastekniskt Center 2012).

The process of anaerobic digestion can take place in several types of reactors and the reaction time varies between 15-100 days depending on the reactor type and substrate type (Svenskt Gastekniskt Center 2014). In Sweden, the most common type is the continuously stirred tank reactor, also called CSTR, and operation temperature of either 37°C (for mesophilic microbes) or 50-55°C (for thermophilic microbes). For a new reactor to work properly it needs to be initiated with a slurry containing healthy microorganisms from another reactor that is already in operation.

Depending on the composition of the substrate, the molecular content of the biogas varies (Svenskt Gastekniskt Center 2014). Usually, a bioreactor fed with a mix of organic compounds generate a gas consisting of 50-70% methane and the rest almost solely carbon dioxide with some small amounts of other gases, such as hydrogen sulphide and water vapor.

4.1 Terminology of anaerobic digestion

There are some concepts that are commonly used in anaerobic digestion and in the calculations of the biogas potential. Below, some of the terms that later will be used are explained by reports from Avfall Sverige and SGC (Avfall Sverige 2009, Svenskt Gastekniskt Center 2012).

- Total Solids (TS): Refers to the organic material as dry weight and is usually expressed as a percentage of the material’s wet weight. Usually indicates the need of dilution to make the material pumpable, which normally is a TS value below 10-15%. There are some exceptions, such as substrates with high fat content. For example, cream has a high fat content and a TS value of 60% but is still easy to lead through a pump.
- Volatile Solids (VS): Signifies how much of the material is combustible at a temperature of 550°C. Generally, high content of VS indicates a high gas yield, which is desirable and could indicate a high organic content of the substrate. However, some material which is not organic might also have high VS. An example is plastic, which is combustible at 550°C and therefore contributes to the VS of the substrate but is not degradable.
- Biogas yield: Expressed as normal cubic meter biogas per weight unit substrate, for example Nm^3/ton TS. Is decided from the content of TS, the degradability of the substrate and the composition in terms of fats, carbohydrates, and protein in the material.
- Methane content: Volumetric percentage of methane in the biogas. Also defines the energy content of the gas since carbon dioxide cannot be combusted.

4.2 The substrate composition

Subchapters 4.2 to 4.4 highlight important aspects that need to be considered when calculating or operating a bioreactor of anaerobic digestion.

The biogas yield highly depends on the substrate composition, and what type of nutrients the organic material consists of. Theoretical values of biogas and methane yields from pure macronutrients can be seen in Table 2. As seen, the biogas yield is highest for fats, and lowest for proteins. Protein as substrate however generates the highest methane content in the gas, whereas a substrate of carbohydrates generates a gas with only 50% methane content.

Table 2. Average biogas yield and methane content from pure macronutrients (Avfall Sverige 2009).

Macronutrient	Biogas Nm^3/kg VS	Methane content %
Fats	1.37	70
Proteins	0.64	80
Carbohydrates	0.84	50

The degradation time also depends on the composition (Avfall Sverige 2009). Starch and proteins degrade fast while the slowest substrate to degrade is cellulose and hemicellulose. Some examples of organic materials with high content of cellulose are straw, paper, and manure. Fats vary in their degradation time. The level of fineness of the material also affects the time of degradation, and a finer material gives a larger surface area for the bacteria to work on and therefore speeds up the process.

In Appendix 4 information about specific types of organic waste used in the model has been gathered by the author. This information, showing both TS-values, biogas yield and the corresponding methane content for each substrate is also what is used to reach the results in this report. The values are experimental results performed at mesophilic process conditions. The type of reactor is not specified in the reports used as basis for the values in the table.

4.3 Optimal conditions for microbial activity

The biogas production depends fully on the activity from the microorganisms, and their well-being is therefore crucial to receive a product (Jarvis and Schnürer 2009). For the production to be efficient, several species of microorganisms are to be active, and they need to have functional collaboration between their separate digestion processes.

A correct mixture of nutrients is the first key to a successful anaerobic digestion (Jarvis and Schnürer 2009). The nutrients come from the substrates that are digested and a combination of substrates is preferred to favour a diversified microbial community. Although it is important that the substrate mix does not vary too much over time since most microorganisms are specialists and grow from a specific substrate. In terms of what the microorganisms require to perform both anabolism and catabolism, the substrate needs to contain four ingredients: energy source, electron receiver, building blocks for new cells and vitamins and minerals (Jarvis and Schnürer 2009).

The quota between carbon and nitrogen in the substrate is also of importance (Avfall Sverige 2009). The optimum range lays between C:N ratio of 15-30. At lower C:N ratio than 10-15 ammonia starts to accumulate, and the mixture obtains a high pH, which could be toxic for the microorganisms. With C:N ratio higher than 30, the digestion pace is slowed down drastically.

Other than the substrate composition, the ambience of the process needs to be in favour for microbial growth. Some parameters that are important to monitor are temperature, pH, oxygen levels and salt concentration (Jarvis and Schnürer 2009). Different species of microorganisms have different preferences regarding the ambience, but to favour as many species as possible, the parameters should be set to a value that suits most microorganisms, maybe not to the optimum habitat, but to the sufficient level of growth.

4.4 Practical challenges

There are different types of practical problems that can occur during anaerobic digestion (Avfall Sverige 2009). Some issues that are common are

- *Foaming:* A mechanical problem that can happen when a large part of the substrate mix consists of fats and is stirred.
- *Sedimentation:* Difference in weight of the substrate material can cause uniform layers in the reactor. Straw and feathers are typical light material that can cause a floating crust while dense material can sediment and remain in the bottom of the reactor. Sedimentation causes shorter residence time, due to smaller reactor volume.
- *Fermentation in the receiving tank*: At high outdoor temperatures there is a risk of fermentation happening before the substrate enters the reactor. This can lead to foaming in the receiving tank.
- *Pumping difficulties:* A pure substrate mix with high TS-value might be difficult to pump and may need added liquid to function. In co-digestion this is not as common.
- *Smell:* Transportation to the bioreactor is the most common source of smell problems. Some substrate is more prone to cause problems than others, such as fish residues and chicken manure. All transport of substrate should therefore be made with closed containers and liquid residues in well-sealed tubes.

4.5 Biogas as a resource

The compounds in the produced biogas depend on the composition of the substrate, as described in earlier subchapters. The energy content of the gas is directly correlated to the methane content of the gas (Svenskt Gastekniskt Center 2014). As mentioned, anaerobic digestion usually produces a gas of about 50-70% methane, and with development of the technique over time, modern bioreactors produce biogas with a methane content of about 65%. The energetic content of a gas with this composition is visualised in the conversion chart in Figure 12. Several of the other data sources found (Chamy and Vivanco 2007, Hjort 2021, Svenskt Gastekniskt Center 2012) also use 65% methane content as an estimation for the gas regardless of substrate composition.

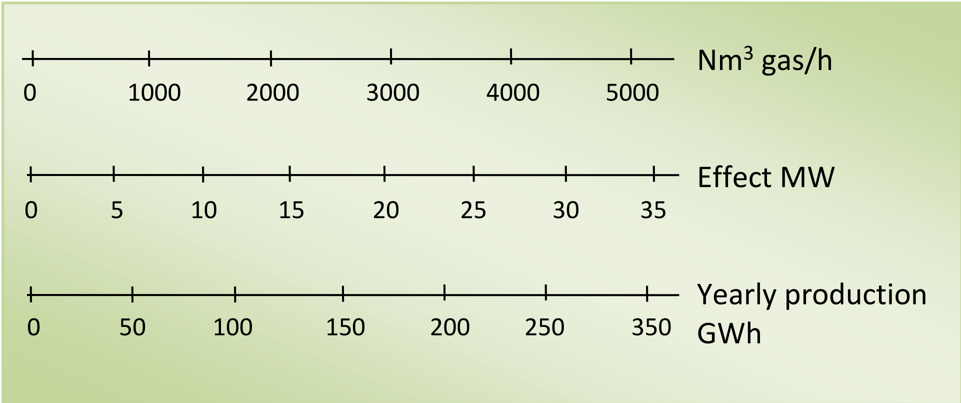

Figure 12. Conversion chart for biogas with a methane content of 65%. Diagram made by author. (Svenskt Gastekniskt Center 2014)

Pure methane has an energy content of 9.97 kWh/Nm^3. In this study, the contribution to the methane content of the gas from each substrate has been taken into consideration, and the gas mixture from different substrate compositions may therefore vary in energy content. The result is therefore presented in both biogas potential as well as energy potential.

Biogas can be used in similar applications as natural gas, such as in systems for heating or electricity generation (EPA 2021). A positive aspect of using biogas from waste to generate electricity, apart from being renewable, is that the power production is plannable and does not depend on weather conditions, as sun- and wind power do (Energigas Sverige 2017). The downside of using biogas for electricity generation is that a large fraction of the energy is lost in conversion. Electricity can be produced by driving a methane-diesel engine with biogas (Arias 2021), but comes with a great loss of the energy content in the gas when converted. The overall energy loss by biogas conversion to electricity varies depending on method but ranges from 15% (boiler) to 80% (internal combustion engine) (Hakawati et al 2017). Calculations regarding biogas conversion to electricity will in this thesis be simplified to having an energy loss of 50%. Note, that if the biogas would be upgraded (as explained in the next paragraph) before it being used for electricity generation, the efficiency would theoretically be higher (Hakawati et al 2017).

For the applications of generating electricity or heat, the raw biogas as a mixture of methane and carbon dioxide can be used directly (Arias 2021). When the biogas is to be distributed through gas grids or used as vehicle fuel, the gas needs to be “upgraded” to increase the energy content (Svenskt Gastekniskt Center 2012). This is done by removing carbon dioxide and other gases to obtain close-to-pure methane gas. A gas of this kind is called biomethane and with 97% methane content biomethane is considered “clean enough”. The separation of carbon dioxide from methane can be done by several techniques, such as Pressure Swing Adsorption (PSA), water scrubbing, chemical absorption, membrane separation or cryogenic separation (Svenskt Gastekniskt Center 2012). Upgrading of the gas can also cause energy losses depending on the technique, the losses are typically just a few percent (Petersson and Wellinger 2009). Calculations regarding upgrading biogas to biomethane in this thesis will for simplicity assume that there are no energy losses included. Worth remembering is that the upgrading process itself also requires energy but is not calculated for in this thesis.

Once upgraded, there is a possibility of using the biomethane as a substitute to natural gas in gas grids, in industrial applications, as raw material for different products such as paint or plastics, or as fuel in powertrains to drive a vehicle (Energigas Sverige 2017). A comparison between biomethane and conventional fuels that are used today is shown in Table 3 below.

Table 3. Fuels and their energy content (Svenskt Gastekniskt Center 2012).

Fuel	Energy content kWh
1 Nm^3 biomethane (97% methane)	9.67
1 Nm^3 natural gas	11.0
1 litre gasoline	9.06
1 litre diesel	9.8
1 litre E85	6.37 (summer) 6.59 (winter)

If the biomethane is used by vehicles it commonly known as vehicle gas. The name vehicle gas does not specify the origin of the gas and does therefore also include natural gas. Biomethane from waste used as vehicle gas has, other than coming from a circular and renewable source, the advantage of low emissions of harmful compounds such as NO_x and particular matter compared to fossil fuels (Energigas Sverige 2017). Moreover, biomethane has close to zero emissions of SO_x compounds.

Biomethane used as vehicle gas also has lower climate impact than fossil vehicle fuels. In a report published by the Swedish Ministry of Energy (Energimyndigheten 2020), biogas from a substrate mixture consisting of mainly sludge, manure, food waste and slaughterhouse waste, has emissions of 12.7 g CO_2-eq/MJ. This can be compared to diesel, that has an emission per energy content of 94.1 g CO_2-eq/MJ. This is illustrated below in Figure 13.

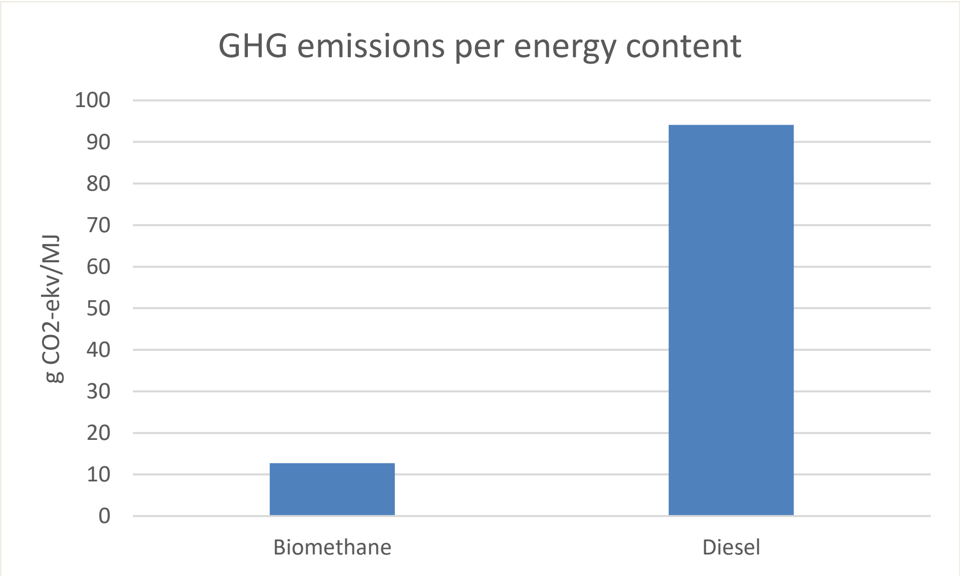

Figure 13. GHG emissions in CO2-eq/MJ per energy content of biomethane and fossil diesel. Diagram is constructed by the author (Energimyndigheten 2020).

With most smaller gas vehicles, for example private cars, the powertrain can usually run on both gas and gasoline (Energigas Sverige 2017), or in combination with diesel in a Methane Diesel Engine (MDE) (Svenskt Gastekniskt Center 2012). In larger vehicles such as buses and trucks, it could be favourable to cool down the biomethane to form a liquified biogas (LBG), to increase the energy content per volume and thereby the driving range (Energigas Sverige 2017). LBG has a slightly higher climate impact than gaseous biomethane. Since natural gas just like upgraded biogas consists of methane, LBG could also be used instead of Liquid Natural Gas (LNG). Ships and larger boats also play important roles in the market of both LBG and LNG.

According to a joint campaign between Avfall Sverige and Swedish municipalities called "Do not make it harder" (Swedish: *Gör det inte svårare*) (Whitehouse and Tauber 2021), a city bus can run a year on biogas from food waste produced by 3 000 people, and a garbage truck on biogas from the food waste produced by 1 200 people, based on Swedish conditions. The year 2018, the food waste per capita was 95 kg in Sweden(Naturvårdsverket 2021), which signifies that a city bus and garbage truck that run on gas has an energetic need of 370 MWh and 120 MWh per year, respectively.

4.6 Other products from anaerobic digestion

The process of anaerobic digestion also generates another versatile subproduct – digestate, which can be used as fertilizer, soil amendment or even as foundation material for bioplastics (EPA 2021). The digestate leaves the reactor as a slurry but can be divided into solids and liquids, of which the treatment and handling can be favourable. Some of the fixed nitrogen in the substrate will also be mineralized during the digestion to ammonium-nitrate, which makes it more accessible for plants, making the digestate optimal as a fertilizer (Avfall Sverige 2009).

It is however important to take into consideration that the substrate for the process is setting the quality not only for the biogas but also for the digestate (Avfall Sverige 2009). Almost all nutrients entering the bioreactor will remain in the digestate, as well as compounds that may be unsuitable for fertilizers. If the digestate is to be valued, it is therefore crucial to investigate if the substrate holds sufficient nutrients and low enough levels of harmful compounds for the digestate to keep the expected standard for its use.

Since the digestate can be used as a fertilizer it could also potentially replace another product, which could lead to a lower carbon footprint of the fertilizer. In this thesis however, the possible lowering of climate impact the replacement of other fertilizers most likely would contribute with has not been taken into the calculations.

5 Waste handling and energy demand research

This chapter will present the findings of literature study and interview study that corresponds to the research of waste handling and energy demand. The current situation in the Metropolitan Region in regards of waste management and challenges, energy market composition, electricity and fuel demand, and environmental goals will be addressed, to understand the possibilities and possible setbacks of organic waste recycling and the segments in where the potential biogas could be of use.

5.1 Waste management

Chile’s 19 million inhabitants produce 7 million tons of waste per year (Arias 2021). About one fifth of all waste, almost 1.5 million tons, is not taken care of and ends up in illegal dumps or is directly dumped in the countryside, in rivers or in the ocean. The remaining 80% of the waste that today is managed, is to the major part disposed in landfills.

5.1.1 Socio-economic challenges

The responsibility of waste management in Chile lays upon industries and municipalities (Bishara 2021) where both parts are eligible to choose whether the treatment should be done locally or if the service should be bought by an external company. Residual waste is managed municipal level and the funds are generally insufficient to make any large technological improvements locally (Arias 2021). The municipal budget is decided by elected representatives, and the cashflow in is dependent on taxes from the inhabitants living in the municipality, as well as industries and businesses located in the area (Bishara 2021). Taxes that may be paid by inhabitants are vehicle taxes, road taxes, and property taxes. Regarding the latter, there are several exemption rules depending on property fiscal value, that are today letting a large portion of the inhabitants (77% on a national level) being exempted from paying property taxes (Ministerio de Medio Ambiente 2020).

Only the owners of the top 23% most expensive properties in Chile are therefore included in the property taxing system and are expected to pay a percentage of their property value to the municipality for the service of waste management. However, according to Arturio Arias at the landfill and waste management company KDM Empresas (Arias 2021), this tax is commonly not paid, and instead delayed. This starts a spiral of debt for the property owners, with an interest rate that makes future payments to the municipality even less likely to happen. Many municipalities in RM, regardless of inhabitant wealth, do therefore not have sufficient funds to pay for external waste management, but have the necessity of external disposal due to high population density. The service of waste management is traditionally provided by a small number of large companies and is usually ordered by municipalities either way, due to lack of other options. As with the property tax, the municipal payments are therefore also often delayed, leaving them in dept to the companies hired to handle the waste. About 50% of the payment from municipalities in RM to KDM Empresas are today delayed, and to the date, some up to 20 months (Arias 2021).

The current price that the municipality must pay for the service recollecting, transporting, and disposing the waste is about 14 USD per ton, which in international standards is a low price for waste handling (Arias 2021). This can be explained by the simplicity of the waste handling process in comparison to other countries, since almost all collected waste in Chile is disposed, unsorted, in a landfill. The cost of disposal corresponds to 25% of the 14 USD, and the rest of the cost is connected to collection and transportation (Ministerio de Medio Ambiente 2020).

The division of responsibility on municipality level and the varying exemptions of property taxes result in inequality of the possibilities of improving the waste management between municipalities (Ávalos 2021). In municipalities where the population is poorer, the other funding is supposed to be sufficient for the municipality to spend on all its responsibilities, such as public school, healthcare, and waste management. In richer municipalities on the contrary, the income from property taxes is higher which permits the waste management to be improved and modernised to a greater extent. There have been governmental discussions regarding adding extra taxes to be able to finance a better waste handling, but due to the already existing incapacity of payment from both inhabitants and municipalities, it could have the contrary effect and worsen the situation (Arias 2021). Also, the general opinion upon adding taxes to the system is not in favour by the population, since majority of the Chilean population have high costs of living compared to income and that corruption occurs on higher instances, making the motivation of taxpaying low among the people.

5.1.2 Waste classification and recycling

In Chile waste is usually classified according to origin, risk, and consistency (Bishara 2021). Common categories of origin are industry, agroforestry, mining, construction, hospital and domestic. Risk is usually only classified as dangerous or not dangerous, according to risk to human health and the environment and consistency is simply divided into solid or liquid where solid waste is traditionally managed by being put in a landfill, while liquid waste must undergo treatment in basins. The regulation of waste management is often depending on the origin classification, where producers often are responsible of their own waste while domestic waste is handled by municipalities. Most municipal waste today, is classified as solid, non-dangerous, domestic waste (SNDW).

There is no law on a national level forcing individuals to recycle any materials from domestic properties nor on municipal level in Chile today (Ávalos 2021). There are however recently released guidelines and goals. The Ministry of Environment published a document the year 2020 called "National Circular Economy Roadmap" (Spanish: *Hoja de Ruta Nacional a la Economía Circular*) (Ministerio del Medio Ambiente 2020). The roadmap holds a 20-year plan, where goals to be reached are for example a 25% decrease of municipal waste per capita since 2018 and an increase of recycled materials in municipal waste to 65% compared to 2018.

Another initiative by the Ministry of Environment is a governmental programme called "Chile Recycles (Spanish: *Chile Recicla*) (Ministerio del Medio Ambiente 2021a), which aims to make recycling accessible for the population. The programme that is providing the inhabitants with information on how, what and where they can recycle. On their webpage two types of drop-off points for waste can be found, the "green points" (Spanish: *punto verde*) and the "clean points" (Spanish: *punto limpio*). The green points are usually a drop-off points for mixed waste or for one or two specific materials, while the clean points usually offer recycling for many types of materials, amongst others, paper, plastics, carton, metal, and glass. At few of the clean points organic material is also collected, but only uncooked organic material of vegetable origin. What types of materials are picked up at the green points and clean points depends on the funding of the site. To the most-part, the points are established on municipal or regional initiative, where the material might be recycled or put in monocultural landfills, which today happens with for example glass, paper, plastics and to some extent liquid organic waste from larger industries such as dairy production or salmon farms (Ávalos 2021). There are also examples where private actors or companies have funded a drop-off point, permitting them to select which materials they are willing to pick up at this specific point. Nationwide there are currently over 7 000 green points and almost 100 clean points open to the public, most of them located in the Metropolitan Region (Ministerio del Medio Ambiente 2021a).

Several municipalities, as well as companies, have recently discovered the economic value of materials earlier classified as SNDW. Today many municipalities offer the option of recycling of specific materials such as glass, paper, and plastics to their inhabitants through green points and clean points, but since they often need to be facilitated and financed by the municipality themselves, there is great variation on the environmental outcome of the implementation (Arias 2021). Often there is not enough money to finance recycling campaigns and the recycling system ends up faulty or confusing to the inhabitants. In municipalities with more funding, the inhabitants may even be offered separate bins to sort out their recyclables in their own homes, while others have a common shaft in each building or floor where the inhabitants have the possibility to leave their recyclables for pick-up once or twice a week. In common between the municipalities is that the system induces recycling only on a level that is depending on voluntary separation of materials, and there is no negative consequence if recycling of the selected materials does not take place (Arias 2021).

The national result however shows that the voluntary approach on recycling has not been functioning flawlessly. A report from the Organisation for Economic Co-operation and Development (OCED 2016), where Chile is a member, stated that Chile was in the bottom two of the member states in terms of materials being recycled, with numbers as low as 4% in 2016. According to the national newspaper *El Mostrador*, the year 2019, 55% of the Chilean municipalities provided the service of recycling for their citizens, but the average volumetric percentage of waste being recycled was only 1.7% (Agenda Pais 2019). Some of the municipalities on the list only recycled 0.6% of their waste. An article in *País Circular* from the same year (Molina and Gonzalez 2019) highlighted the challenges of recycling municipal waste by presenting number of recycled plastics. 8% of all plastic was being recycled, but only 17% of these come from residents.

The Chilean Ministry of Environment has addressed the issue and implemented the new law of Extended Producer Responsibility (Ministerio del Medio Ambiente 2017) also known in Chile as the REP law, (Spanish: *Ley REP*) in the end of 2017, making it mandatory for producers of certain products to be responsible of the recycling of valuable materials (Bishara 2021). This law however does not cover all valuable materials and only refers to specific products, such as electronic devices, batteries, packaging materials, newspapers, tires, and lubricating oils, and that their producers are responsible for making sure there are ways to recycle the materials in their products as well as financing the recycling.

Once the recyclable materials and products under the REP law have been separated from the waste, the valued materials are usually arriving mixed in garbage truck or by train to the waste management company (Arias 2021). The materials are then sorted out by hand, even at the largest waste management company in Chile, as can be seen in Figure 14 (left). It is afterwards pressed together to form a cube as seen in Figure 14 (right) and then stored until picked up by the buyer. If the material falls under the REP law and cannot be separated in this manner, other methods funded by the producer may be used.

Figure 14. Recyclable waste arriving to KDM Empresas (left) and stored recycled paper (right) (Source: Author)

Although the products will be separated according to the REP law, and that the cost of separation will be covered by the producer, what happens once separated also depends on if there are any buyers that are willing to pay for the material (Arias 2021). This means that even though the REP law should ensure that the producer takes responsibility for the recycling of their products, there are still some materials that are lost in this system highly depending on economical profit by the waste handling company. As an example, from Arturio Arias at KDM Empresas (Arias 2021), a producer of food packaging materials present in Chile pays just enough for the separation but is not willing to pay almost anything to buy back their own products. It is therefore not economically profitable for the company to press and store their material for free and today their products therefore end up in the landfill instead.

Other companies specialized in providing recycling solutions for both companies and municipalities have emerged in recent years and are now competing with the traditional landfill owners. An example is the company TriCiclos, which was a pioneer company with their vision of circular economy already in 2009 (Agustin Correa 2021). Today they get hired directly by bigger stores and industries to find the correct and best way to recycle materials, but also by municipalities to set up recycling stations. TriCiclos as an example work almost exclusively with products and materials that are covered by the REP law, mainly because they can gain economic value from both the service they provide to the customer, as well as the material they sell back to the companies.

5.1.3 Organic waste recovery

Organic waste can be found in several classification categories. Regarding origin it can be classified as for example industrial, agroforest or domestic waste, and as to consistency it may be of both solid and liquid character (Ávalos 2021, Pino 2021). Usually, the risk factor of organic waste is considered not dangerous. Since organic residues can hold different characteristics, the regulations and recommendations on its recycling is complicated. Industrial and agroforest waste producers have different responsibility in terms of for example declaration of their waste than municipalities, but transparency on the matter towards the public is not common practice. Municipalities have almost to no responsibility in terms of declaration of waste classified as not dangerous and most organic matter in municipal waste is instead classified as SNDW. Companies producing residues that can be considered assimilable to SNDW can also buy the service from municipalities to pick up their waste. This means that for example restaurants, small agricultural industries, and supermarkets, although having a rather clean waste flow of organic matter, classify all their organic waste as assimilable to SNDW (Ávalos 2021, Pino 2021).

Although the challenge that comes with recycling organic waste since it holds a non-unified classification, there are examples of initiatives on municipal level where the engagement in the matter has been high with great outcome, for example in the municipality in La Pintana, in RM (Marchant 2021). La Pintana is a municipality which historically has faced problems with criminality (Ramos 2019), and the municipality is classified as semi-urban with a population of about 180 000 people in an area of 31 km^2 (Gobierno Regional Metropolitano de Santiago 2017). Although the rather high population density, and socio-economic challenges, the governing body of La Pintana started working with environmental issues as early as in the 1990s, when they implemented a municipal department of environment, known as DIGA (Ramos 2019). Since then, they have accomplished to promote separation of waste in the households and organic waste has been put on a municipal compost, of which the nutrient rich product has been rewarded to inhabitants free of charge. Today there is also an ongoing pilot project on producing biogas from the organic waste, in collaboration with a local university (Marchant 2021). La Pintana was mentioned as an example in several interviews during this study, as well as in national newspaper, as a role model for Chilean municipalities and that it is possible to change the waste system without excessive external funding (Miranda and Mendez 2021, Pino 2021, Ramos 2019).

There are also companies focusing on specific organic waste treatment. As an example, the company Schwager Energy in Chile that originally had their focus on engineering within copper mining, ten years ago started working with bioreactors due to their high competence of energy engineering (Gutiérrez 2021). The concept of anaerobic digestion was by then completely new in Chile. Several projects with biogas have since been conducted by Schwager Energy, with substrate varying from chicken manure and fruit residues to dairy food production residues. Today, they are among few national companies with knowledge of anaerobic digestion, and they currently have three bioreactors running in Chile. They also have a new project ongoing in the city Osorno in the south of Chile, where collaboration with one of the gas distributors in Chile, Gasco, is planned. The gas from this plant will be used to generate steam. None of the bioreactors Schwager Energy handles today are located in RM.

On a national level, the interest in organic waste recovery has not until recently reached the spotlight. The focus has instead been on lowering the greenhouse gas (GHG) emissions, and this is also where a governmental collaboration with Canada that started 20 years ago (Ministerio del Medio Ambiente 2021b). In 2017, the collaboration established to a 5-year programme called Recycle Organics (Spanish: *Reciclo orgánicos*), which aims to lower GHG emissions by reducing the quantity of organic waste in landfills and promoting composting and anaerobic digestion. According to the programme, by implementing these changes, 70% of GHG emissions from the waste sector in Chile could be decreased. Small projects within the programme have taken place since the start 2017, but due to nationwide political uncertainties during the year 2019 as well as the covid-19 pandemic affecting the Chilean economy gravely, many projects have been paused and not until recently resumed (Canales 2021).

The 19th of March 2021, the National Strategy on Organic Residues (ENRO) (Spanish: *Estrategia Nacional de Residuos Orgánicos*) was officially launched (Ministerio de Medio Ambiente 2020, Pino 2021). ENRO is also a result from the governmental collaboration between Canada and Chile and is implemented through the international company Arcadis. The document of the strategy holds a 20-year plan of how to recuperate organic matter that today ends up in landfills, but there are few concrete steps that can be enforced by local authorities. ENRO almost exclusively suggests compost as a treatment method for organic waste, and that it preferrable should be implemented on domestic level or in neighbourhoods. They also suggest an increase of educational establishments on compost, and that public institutes should separate organic residues. According to the strategy, this should make it possible to recover 66% of municipal organic waste by 2040, compared to 1% that is today.

Initiatives regarding organic waste recycling have also been seen earlier at the end-line of waste management. The year 2007, KDM Empresas performed extensive economical evaluations on treatment of organic waste together with the IVL Swedish Environmental Research Institute, investigating alternatives including separation on-site with direct treatment of the organic matter as well as recuperating energy by extracting gas caused by anaerobic digestion from the landfill (Arias 2021). The outcome was that the cost of organic waste separation would be too high for the profit that could be generated. Instead, the most economical profitable option was to continue disposing mixed municipal waste containing organic matter and instead extract the landfill gas for electricity generation. The company decided to go through with the project 2011 and today they extract about 9 400 Nm^3 landfill gas per hour, clean it through water scrubbing, activated carbon adsorption and PSA to remove impurities before generating electricity through nineteen Methane-Diesel-engines of 1.4 MW each. The process does not work flawlessly, and since the substrate for the anaerobic digestion holds low quality, so does the gas. The most important impurities to remove from the landfill gas according to Arias are siloxanes (Arias 2021), which are compounds that holds a Si-O-Si linkage in the molecular structure. A paper published in the US National Centre for Biotechnology Information (Li et al 2019) confirms that siloxanes cause severe damage on the piping system as well as the engines and are commonly found in landfill gas where food waste is mixed with personal hygiene products, surface treatment formulas and fabric softeners. The engines at KDM Empresas are the most expensive to repair and replace, and the cleaning process is therefore extensive but does not save the piping from damage, which therefore must be renewed on common basis. Although the removal of most siloxane, some remains when the gas reaches the engines, meaning that there are constantly some engines that are undergoing reparation. Often only fourteen to sixteen of the nineteen engines are therefore simultaneously running to produce electricity, which elevates to the total cost of the process.

Today, the landfill gas extraction is on the edge of not generating economical profit, which was not the case when the project started (Arias 2021). There are two principal reasons of why, both having to do with the rapid growth of wind- and solar power. When the project started in 2011, the government provided certificates for all types of green energy producers, and by then wind- and solar power were both expensive and uncommon in Chile. The governmental strategy for renewable energy has since then changed, focusing almost solely on wind- and solar power, which has led to that the landfill gas extraction do no longer obtain any renewable energy certificate generating extra income. The second reason is that electricity prices since 2007 has dropped remarkably, and that the economic analyses pointing towards electricity generation made then do no not correspond to the current situation. KDM Empresas are therefore investigating new options of organic waste management, but Arturio Arias do not believe that the discarded options from some years back would generate sufficient income for the company to make an inversion (Arias 2021). The discussions today lean towards a collaboration with a close-by compost company called Armony, where a possible separation of selected organic materials could generate a small profit when sold as substrate to the compost. The option that is currently being investigated is mechanical separation, to avoid the higher costs associated with manual separation by hand.

5.2 Energy profile

The matrix of primary energy in Chile differs principally from the world average by not using any energy from nuclear power plants, by using less natural gas and hydraulic power, and significantly by using more wood and biomass (Ministerio de Energía 2015) as seen in Figure 15 below. The usage of wood and biomass is done in traditional manner which means using mainly untreated wood that is burned in chimneys or stoves to generate heat (Ávalos 2021). Burning untreated wood emits among other compounds, fine particles ($PM_{2.5}$) to the air which can cause smog and acid rain (Danish Ecological Council 2016). Several projects by the Chilean Ministry of Energy are therefore taking place in densely populated areas, to change from traditional usage of biomass for heating purposes, to modern methods, such as providing heating from pellets or electricity, to lower the high volumes of emitted particles (Ávalos 2021).

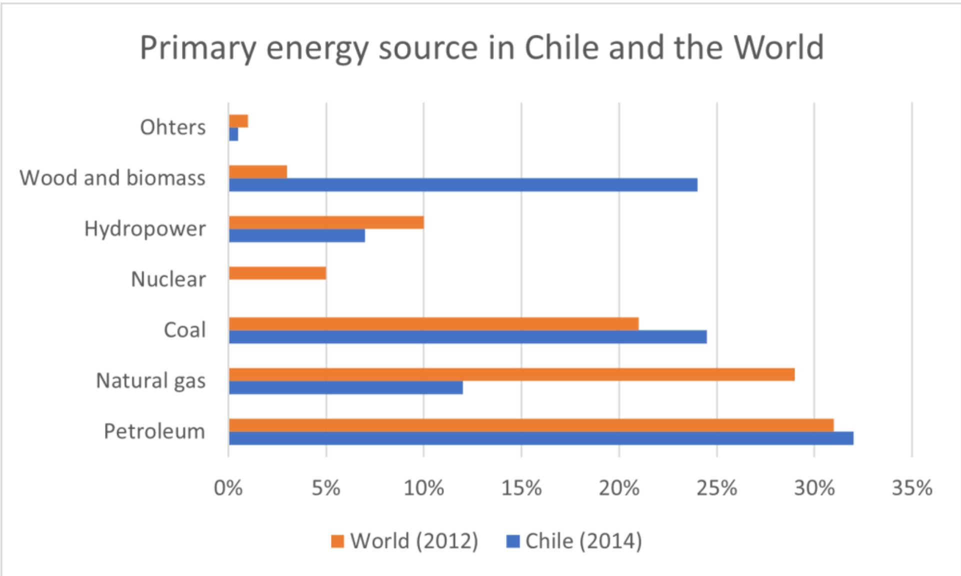

Figure 15. Primary Energy matrix in Chile 2014 (blue) compared to the rest of the world 2012 (orange). Diagram constructed by the author. (Ministerio de Energía 2015)

The sector that uses the most energy in Chile is *Industry and Mining (IM)* (39%), followed by *Transportation* (36%) and the *Commercial, Public and Residential (CPR)* sector (22%) (Ávalos 2021). Out of the mentioned, numbers from 2014 shows that the sector that use most biomass as primary energy is CPR (32%), followed by IM (20%) (Ministerio de Energía

2015). The transportation sector uses almost exclusively (99%) fossil fuels derived from petroleum (Ministerio de Energía 2015).

Chilean homes in 2018 on average consumed 8 083 kWh of energy (Ministerio de Energía 2019a). The division on contribution to the consumption per energy source can be seen in Figure 16.

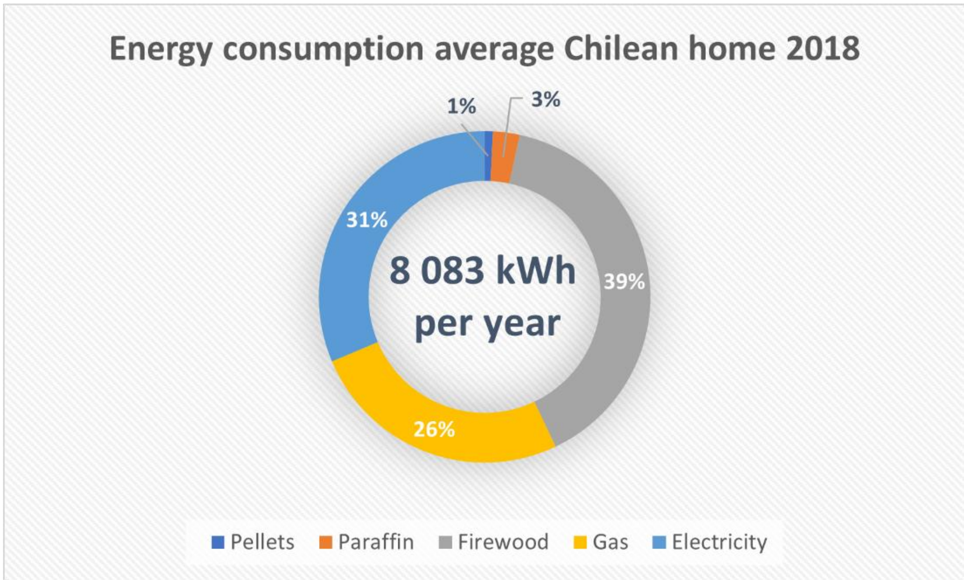

Figure 16. Domestic energy consumption per energy source in Chile 2018. Diagram constructed by the author. (Ministerio de Energía 2019a)

The greatest contributors to residential energy consumption 2018 were firewood (39%), electricity (31%) and gas (26%), which contributed with 3 150 kWh, 2 510 kWh and 2 100 kWh respectively (Ministerio de Energía 2019a).

5.2.1 Electricity production

Chile's electricity profile has undergone many changes during the last half century. Historically the electricity profile had a high percentage of renewable energy, primarily from hydropower. In the 1980s hydropower accounted for almost 80% of the electricity generation Chile (Ministerio de Energía 2015) and was complemented mainly by thermal energy from coal power plants (Ávalos 2021). Over the years, the electricity generation has changed, and the participation of renewable energy sources has been decreasing. As seen in Figure 17 below, the division today between fossil and renewable energy generation is almost equal, with 46.5% renewable energy in 2020. Important to notice is that the contributions per technology in Figure 17 is expressed in percentage. In total, the electricity production has increased, and the apparent decrease of hydropower seen in Figure 17 is not as drastic in absolute numbers, see Figure 22 further down for actual electricity production over the same period.

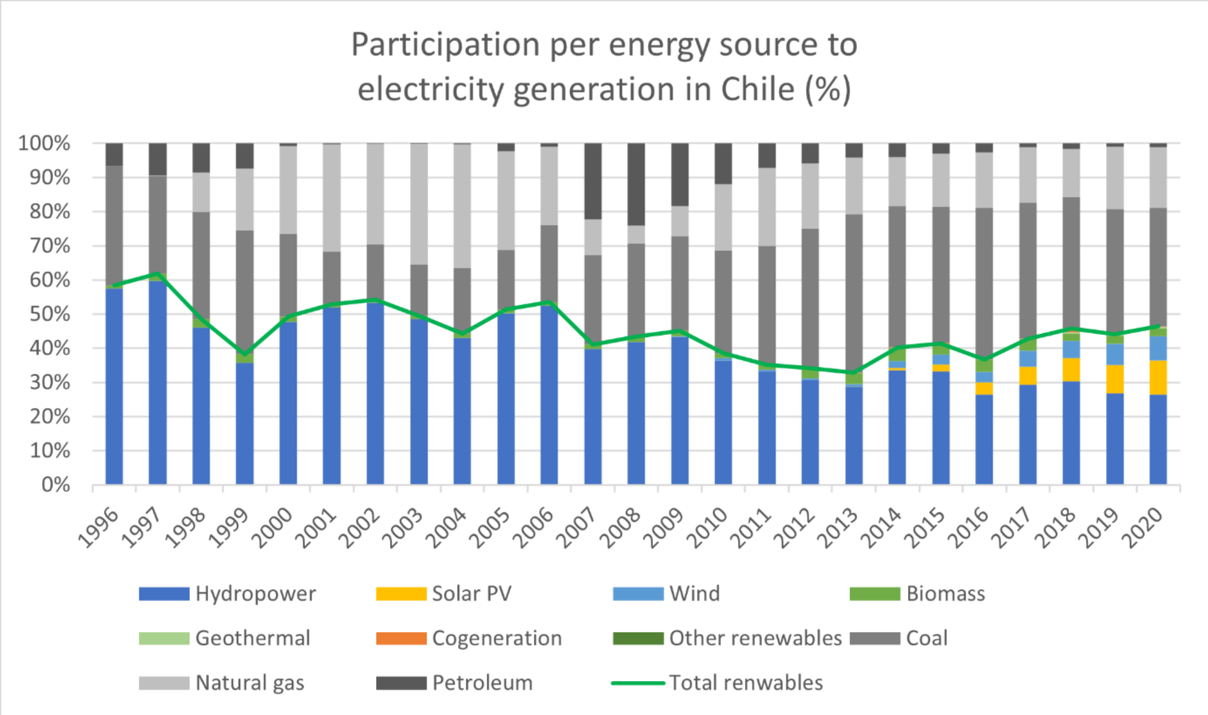

Figure 17. Generation in percentage from different technologies to the electricity generation in Chile between 1996-2020. Diagram constructed by author. (Generadoras de Chile 2021)

Other renewable energy sources in the form of wind power and solar power were introduced to the system about ten years ago and is today a small but rapidly growing part of the national electricity production (Ávalos 2021). The division between energy sources today, updated February 2021, of installed capacity for electricity production can be seen in the diagram in Figure 18 (ACERA 2021). The quota of renewable energy sources has once again increased and is once again producing more than half or Chile's electricity.

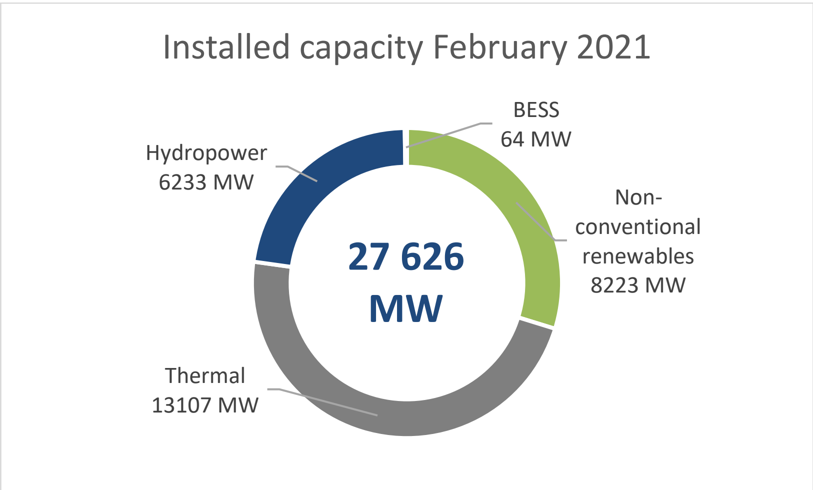

Figure 18. Electricity profile of Chile February 2021. Diagram constructed by the author. (ACERA 2021)

Table 4 presents the installed effect of electricity production in detail. Today's largest contributors to the system are still hydropower, natural gas and coal followed closely by solar power (ACERA 2021).

Table 4. Installed capacity of electricity production in Chile 2021 per technology type (ACERA 2021).

Technology	Net potential (MW)	Net potential (%)	Classification
Biogas	66	0.20%	NC Renewable
Biomass	414	1.50%	NC Renewable
Wind	3025	10.60%	NC Renewable
Geothermal	81	0.30%	NC Renewable
Mini Hydropower (River)	588	2.10%	NC Renewable
Solar photovoltaic	4839	17.00%	NC Renewable
Thermosolar	110	0.40%	NC Renewable
Hydropower (Basin)	3434	12.00%	Conventional Hydropower
Hydropower (River)	2799	9.80%	Conventional Hydropower
Coal	4589	16.10%	Thermal
Cogeneration	18	0.10%	Thermal
Fuel Oil No. 6	142	0.50%	Thermal
Natural Gas	4860	17.00%	Thermal
Petroleum Diesel	3324	11.70%	Thermal
Propane	14	0.10%	Thermal
Liquid gas of Petroleum	52	0.20%	Thermal
Coal (National strategic reserve)	113	0.40%	Thermal
Battery & Energy Storage System	64	0.20%	BESS
Total general	**28532**	**100.00%**	**-**

Worth noting from Table 4 is the installed effect of biogas, 66 MW, which makes up 0.2% of the total installed effect in the country, as well as natural gas, making up 17%. The division of electricity production also differs depending on region, due to the different posibilities and advantages of the landscape. Figure 19 presents the installed effect of non-conventional renewable energy sources divided per region in Chile from February 2021.

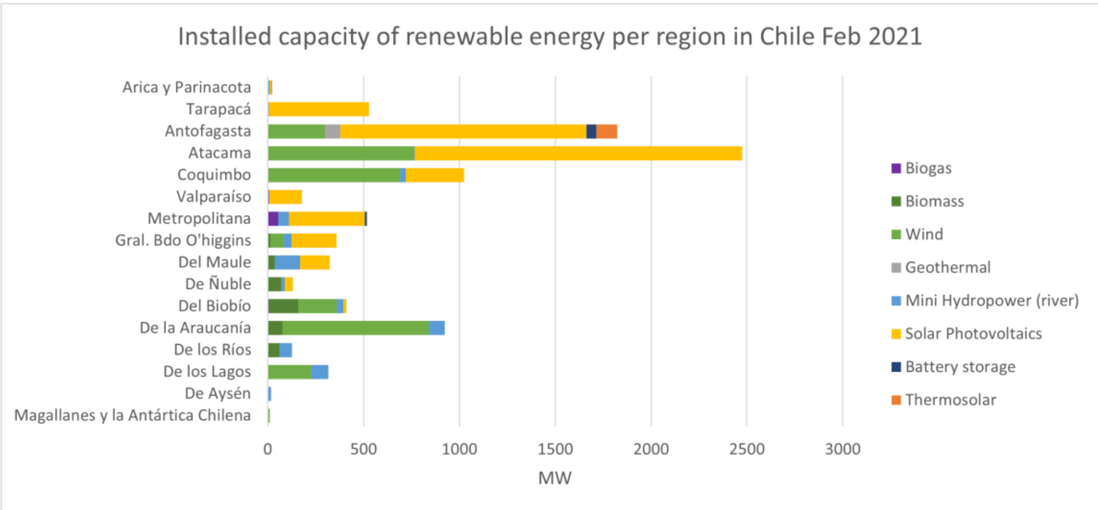

Figure 19. The installed effect of non-conventional renewable energy sources per region in Chile 2021. Diagram constructed by author (ACERA 2021).

The regions are presented from north to south in Figure 19 and by first glance it is seen that the northern regions of Chile have more hours of sunlight than the south (more installed solar power) and that the middle to south of the country has a denser vegetation as well as colder and wetter climate (more biomass and hydropower plants. What is also notable from Figure 19 is that installed facilities of biogas production is only found in RM.

The percentage of installed effect from non-conventional renewable energy has grown from 4% to almost 30% the last ten years (ACERA 2021). The accumulated installed effect from different sources of non-conventional renewable energy sources from 2011 until today can be seen in Figure 20.

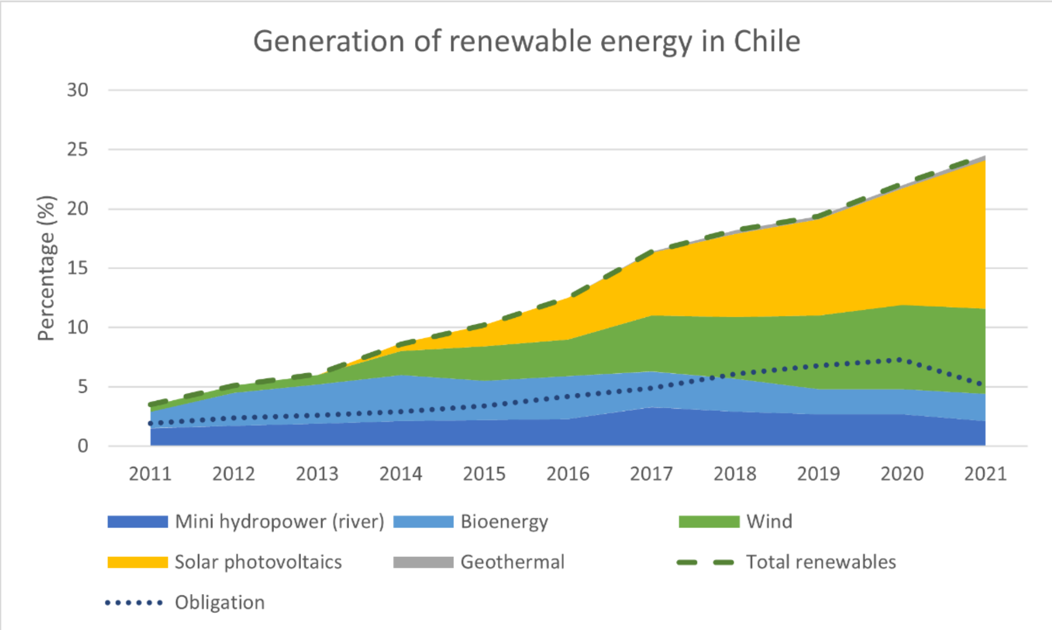

Figure 20. Percentage of installed effect of non-conventional renewable energy sources in Chile 2011-2021. The percentage is of the total installed capacity in the nation. Diagram constructed by the author (ACERA 2021).

Seen in the Figure 20, the percentage of bioenergy in the electricity mix has decreased since 2016. This, however, does not mean that the absolute value of bioenergy has decreased. The next graph, Figure 21, shows the net potential in MW of the installed capacity that are in use, of different technologies of non-conventional renewable energy sources. From this graph it can be read that the installed capacity of biomass has remained almost constant with a slight increase since 2016 (463 MW) to 2021 (480 MW).

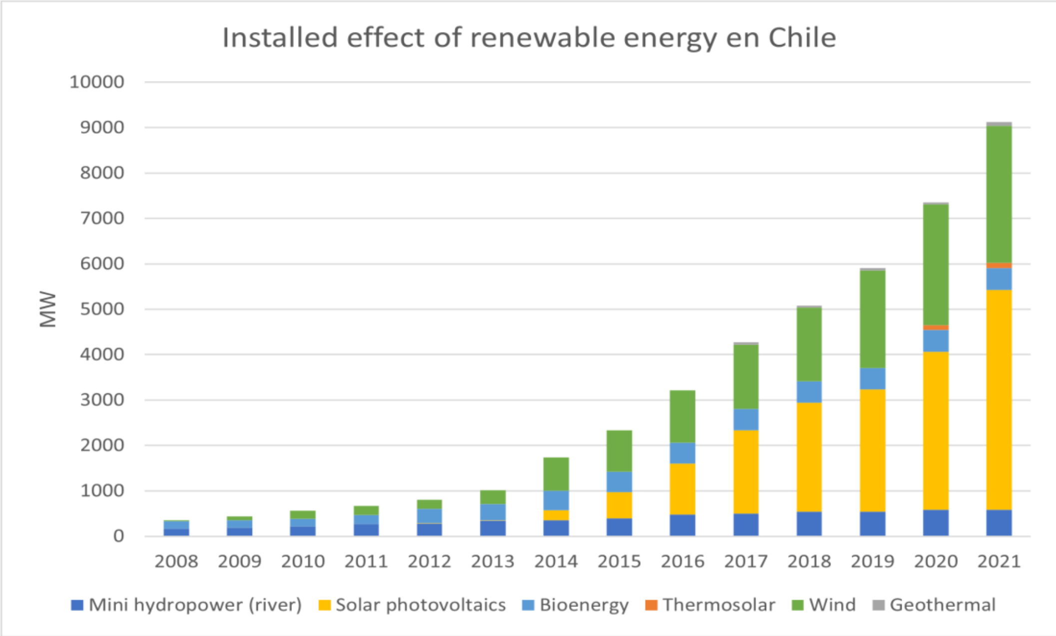

Figure 21. Net potential of installed capacity of non-conventional renewable energy sources in Chile 2008-2021. Diagram constructed by the author (ACERA 2021).

The total energy generation in GWh per year can be seen in Figure 22, including non-renewable sources (Generadoras de Chile 2021). The green line represents the renewable energy produced. Due to the intermittent nature of wind and solar power generation, the graph of generated energy differs from the graph of installed effect in Figure 21 above. This is the case since the installed effect is not operating on full capacity always. The graph in Figure 22 shows that in total 77 800 GWh are generated yearly, and that fossil fuels are still an important part of the Chilean energy matrix.

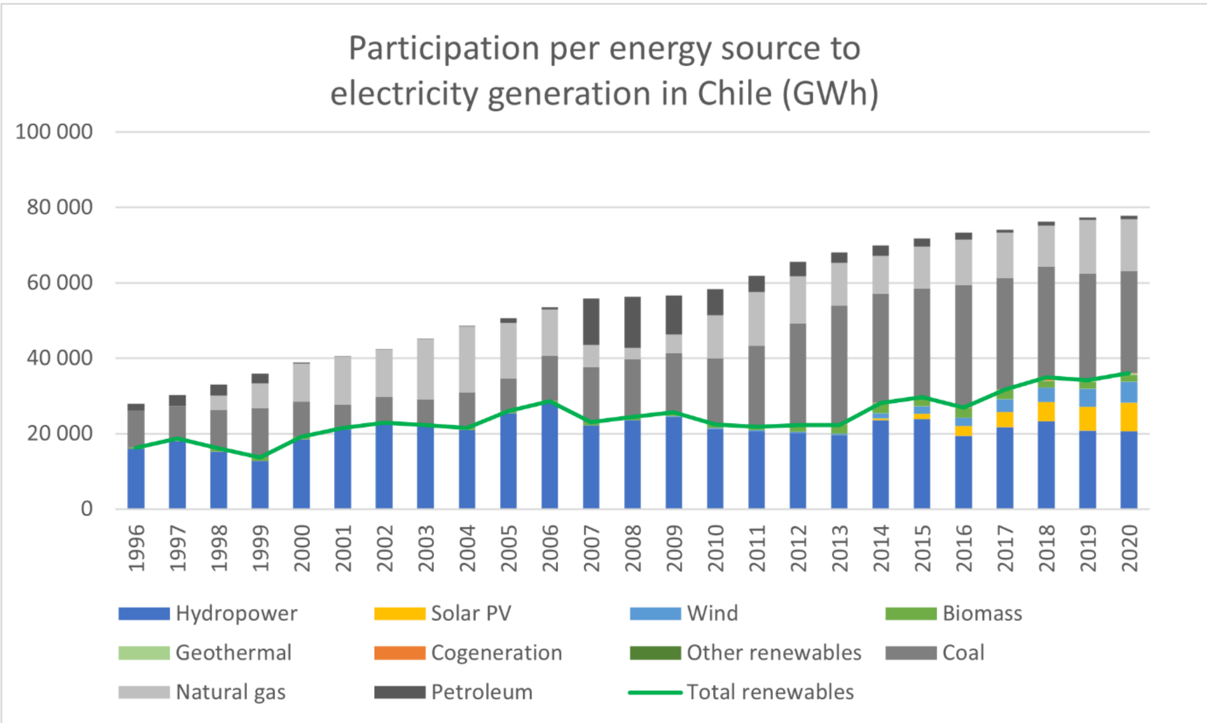

Figure 22. Generation in GWh per year in Chile from different technologies 1996-2020. Diagram constructed by author. (Generadoras de Chile 2021)

5.2.2 Transportation and fuels

In 2019, the total number of road vehicles registered in Chile was almost 5.6 million according to The National Institute of Statistics in Chile (INE 2019b), where most were vehicles for private use according to Figure 23. Road vehicles in Chile 2019 divided on use. Diagram made by the author. (INE 2019b).

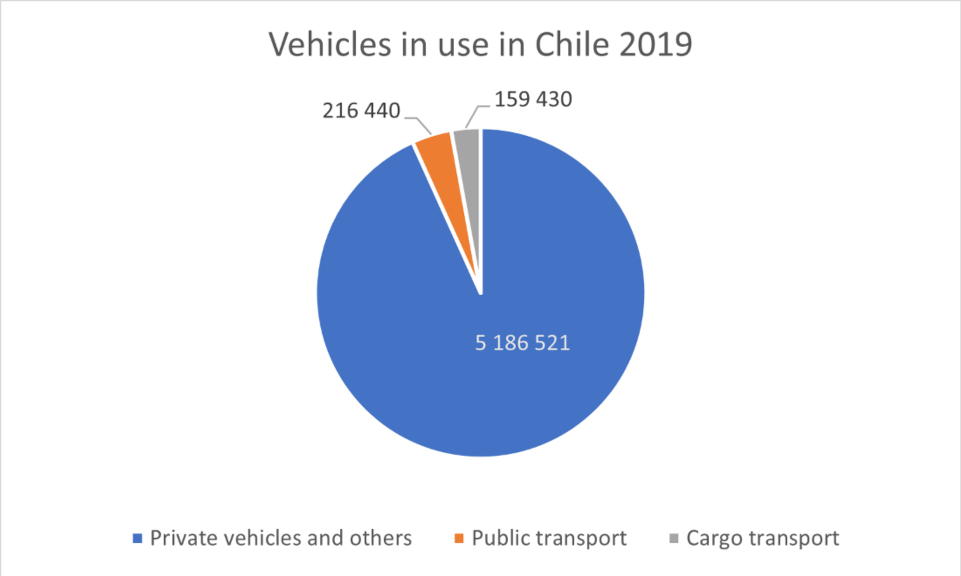

Figure 23. Road vehicles in Chile 2019 divided on use. Diagram made by the author. (INE 2019b)

By looking into the numbers of road vehicles in public transport in Chile, the division between vehicle type is as seen in Figure 24. The orange stacks represent national numbers while the green stacks represent the number of vehicles in RM.

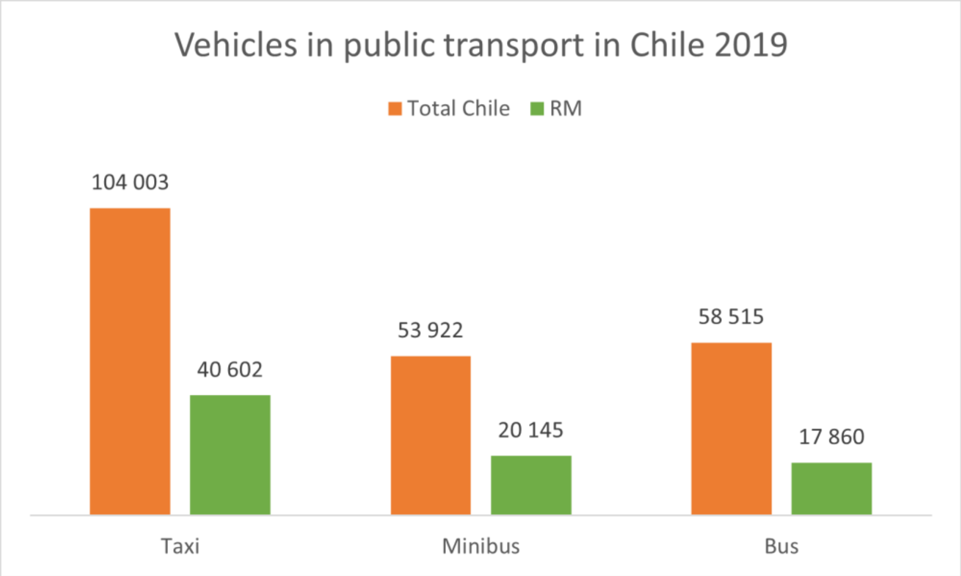

Figure 24. Road vehicles in public transport in Chile 2019. Diagram made by the author. (INE 2019b)

From the diagram in Figure 24, it is seen that taxis make up almost half of the public transport fleet, both nationwide and in RM. Shared taxis in Chile are operating along routes and are usually privately owned. They are a common way of transportation in Chile, since they often are operating later hours than minibuses and buses and is still an economical (but slightly more expensive) option compared to private transportation. This, in combination that they only take a maximum of four passengers at the time, might be the explanation of the high number.

The number of vehicles in cargo transport in Chile 2019 depending on vehicle type can be seen in Figure 25. The grey stacks represent the national number, and the green stacks once again represent the number in RM. Trucks are dominating the cargo transport sector followed by trailers on both national level and in the Metropolitan Region.

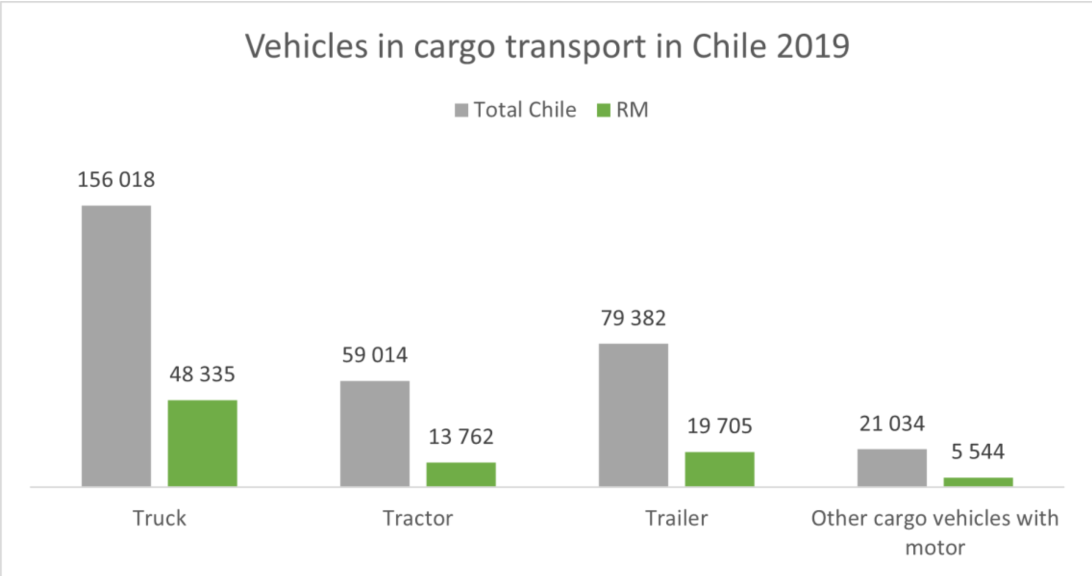

Figure 25. Road vehicles in cargo transport in Chile and RM 2019 divided on vehicle type. Diagram made by author (INE 2019b)

Garbage trucks are a part of the cargo transport in Chile. The company that owns the largest landfill in the Metropolitan Region, KDM Empresas, has 550 garbage trucks circulating the country (mainly in RM) picking up waste (Arias 2021). In total they have about 800 trucks in the company.

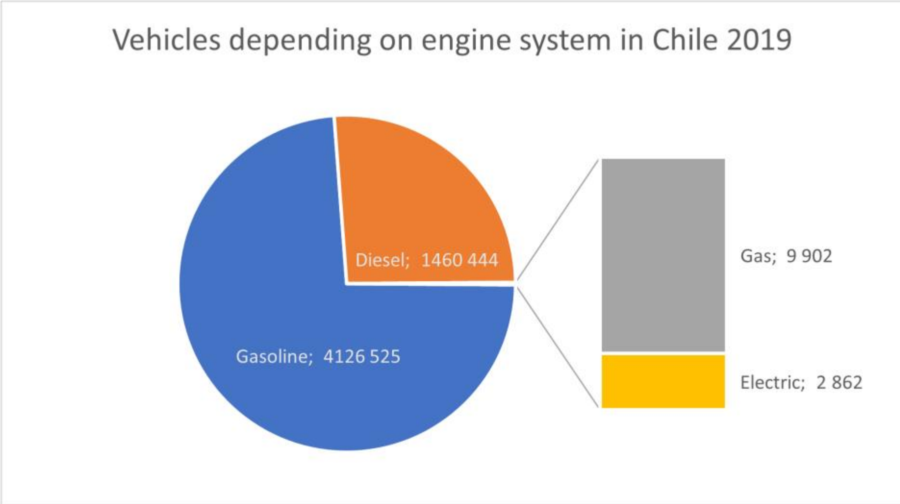

Figure 26. Division of road vehicles depending on vehicle type in Chile 2019. Diagram made by author. (INE 2019b)

Most common powertrain system in vehicles in Chile 2019 was gasoline engines, followed by diesel engines, as can be seen in Figure 26. The division between engine types is similar in RM to the national division as seen in Figure 27. Gas engine systems are uncommon both in Chile, and the Metropolitan Region, with less than 10 000 gas vehicles in the country, making up 0.18% of the total number of vehicles. The most common systems in Chile are gasoline and diesel engines, which both are driven with fossil fuels. A grand majority (99%) of the fossil fuels used in Chile today are imported (Ávalos 2021). The remaining 1% of fossil fuels used nationally comes from extraction of coal and natural gas in southern regions. Chile imports both unrefined oil and oil refinery products, mainly from the United States and Colombia (Energia Abierta 2020).

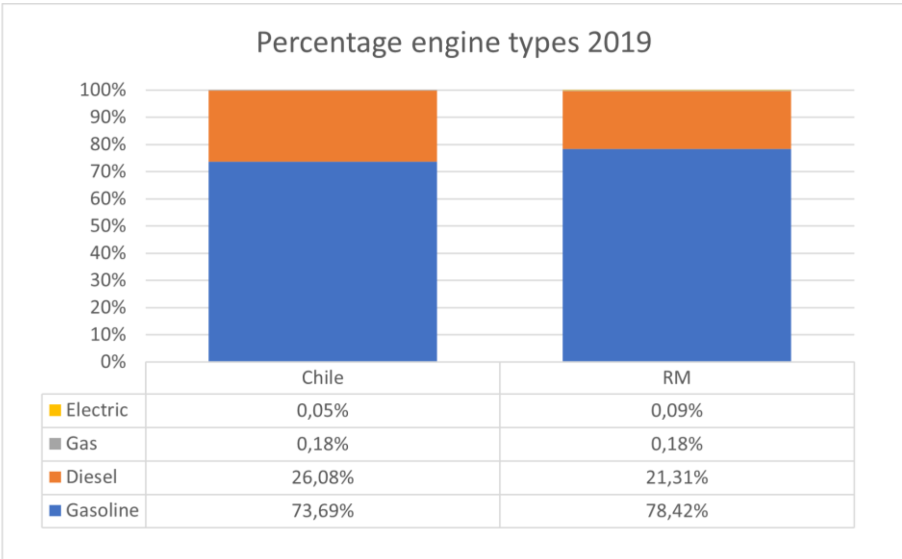

Figure 27. Representation of different engine systems in vehicles in Chile and RM 2019. Diagram made by the author (INE 2019b)

The data from INE does not specify which vehicle types (private, public or cargo) use gas as their engine system, and this information was difficult to find during the study. The author reached out to several bus and truck producers active in Chile regarding their engine systems and received one sole answer from Scania (Luchessi 2021). Without providing any specific numbers, the answer was given that they do have limited amounts of units operating with compressed natural gas (CNG), but mostly uses diesel engines. Biogas was not something used in their engines today.

What the transportation sector will look like in the future remains to be unravelled. Viviana Ávalos at the Ministry of Energy in Chile (Ávalos 2021) foresees that the transport sector in Chile will go through a rapid change towards electrification within a near future. The Ministry of Energy has a goal of reaching 2 430 electrical vehicles (EV) by the end of year 2022, which would be an increase of 10 times the number when the goal was set 2018 (Ministerio de Energía 2019b). The latest report that was released in December 2019 is indicating increasing numbers, as 1 164 EV were registered to the date, whereof 63% light weight vehicles such as passenger cars. INE registered 2 862 chargeable vehicles nationwide in 2019 (INE 2019b), but this number also included vehicles with a hybrid powertrain system. 68% of the chargeable vehicles were also registered in the Metropolitan Region (INE 2019b) which goes in line with the fact that by the end of 2019, 112 public charging stations were installed, where over half of them were found within the borders of RM (Ministerio de Energía 2019b).

Another current national focus in Chile is on hydrogen production, which would permit fuel cell systems becoming an important part of Chilean engine systems in the future (Ávalos 2021). Due to the governmental focus on electrification and within the transportation sector and planned hydrogen production, Ávalos believes that biogas might do better in other segments of the Chilean society, as for example where natural gas today play an important role.

5.2.3 Gas market

The types of gas in the Chilean market are according to the National Commission on Energy (CNE 2021), natural gas (98%), landfill gas (1.5%), air mixed with natural gas (1%) and propane (0.2%). Chile imports over 70% of its natural gas (GascoEduca 2021) from Argentina, the United States and Australia (Energia Abierta 2020). In 2009 the first centrals for regasification of liquified natural gas (LNG) opened, enabling Chile to import greater amounts from a broader market (GascoEduca 2021).

The gas market in Chile today controlled by few but large companies, making it difficult for small actors to enter the market and to compete (Arias 2021, Canales 2021). The gas is distributed to customers in Chile through gas grids and cylinders where the principal consumers are industries (58%), residential buildings (32%) and commercial buildings (10%).

Some companies distribute their gas through gas grids, which can be seen below in Figure 28, the number of clients that receives gas through networks with concession per company in Chile 2013 (CNE 2021).

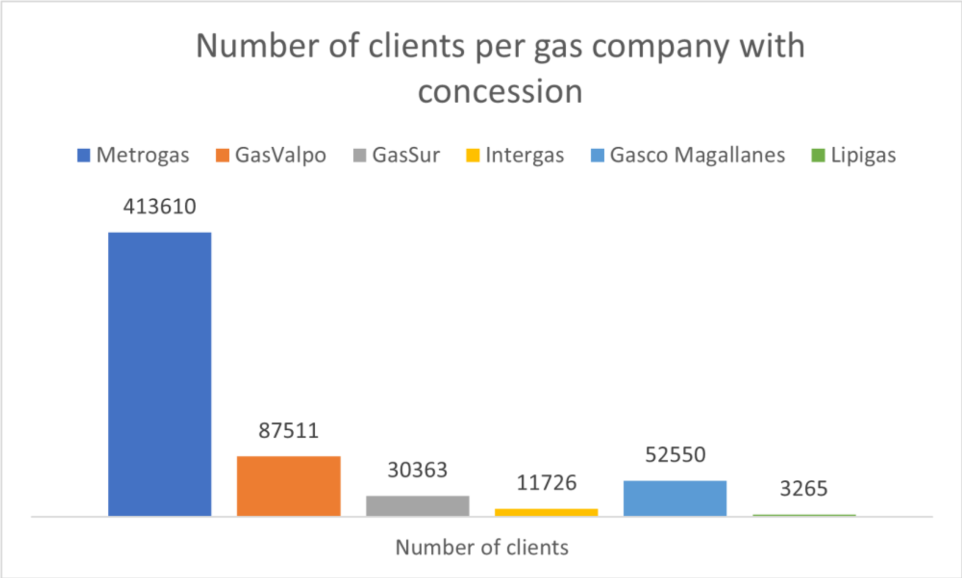

Figure 28. Number of clients per company providing gas through grids with concession 2013. Diagram made by author. (CNE 2021)

There are also grids without concession, which deliver gas to about 330 000 clients in Chile (CNE 2021). Combined, there are networks of gas distribution in ten of the sixteen regions and over one million Nm^3 gas is delivered through grids yearly.

The company Metrogas which is the largest gas distribution company in Chile, started a collaboration of biogas production in 2009 with the company Aguas Andinas, in the outskirts of the Metropolitan Region (Metrogas 2009). Aguas Andinas is the largest water treatment company in Chile and treats wastewater from about half of the Chilean population (Aguas Andinas 2021). By the start of the project, piping was installed to deliver the biogas produced in the water treatment plant La Farfana, and to the refinery facilities owned by Metrogas in the centre of Santiago (Metrogas 2009). It is however unclear if this project is still running, since no articles on the subject has been found from later than 2011 by the author, neither has answers been received from Aguas Andinas, nor Metrogas.

Liquified gas is also distributed in Chile through cylinders by four companies and in 2013, 718 000 ton liquified gas was delivered in cylinders (CNE 2021). Cylinders can be bought in various sizes and are used in industry or for residential purposes, such as cooking or heating (Gutiérrez 2021). The cylinders usually contain propane or butane, or a mixture of the two (CNE 2021).

5.2.4 Environmental guidelines and regulations

The Ministry of Energy is looking into several solutions to reach carbon neutrality in the electricity production (Ávalos 2021). The focus has been on solar and wind energy, but also on energy storage and hydrogen production. A national goal on hydrogen production is to be an international supplier by the year 2030. The main reason for the interest in hydrogen is the economical aspect, as it seems to be among the most profitable of the options for a carbon neutral future. By becoming an international actor on the hydrogen market, the ministry believes there is hope for Chile to change the overrepresentation of fossil fuel importation, to become a net exporter of clean energy (Ávalos 2021).

A decree National Policy on Energy (Spanish: *Política Energética Nacional*) of the Chilean energy market 2050, was first published in 2015 and is currently being revised (Ministerio de Energía 2015). A new version is to be expected during 2021. According to the decree the energy sector should be reliable, sustainable, including and competitive and to fulfil the vision, four pillars are presented:

1) Secure and qualitative energy
2) Energy as driving force of development
3) Energy production compatible with the environment
4) Efficiency and energy education

Within pillar 3, some subgoals related to renewable energy are presented (Ministerio de Energía 2015). The national energy matrix should for example consist of at least 60% renewable energy by 2035 and of 70% renewable energy by 2050. Another sub-goal is reducing greenhouse gas emissions by 30% compared to of those 2007, already by the year 2030. Some concrete steps have been taken to reach the goals where one example is the action taken on coal-based power plants (Ávalos 2021). Today, it is no longer possible to construct any new coal power plants, some of the oldest have been taken out of production, and by the year 2040, all coal power plants are to be shut down.

The greenhouse gas emissions per sector from 1990-2018 (not all years) was presented in a report of the national inventory of greenhouse gas emissions INGEI (Spanish: *Inventario Nacional de Gases con Efecto Invernadero)* (Ministerio del Medio Ambiente 2019) in 2018 and the result can be seen in Figure 29. As seen, although the publication of the National Policy on Energy took place 2015, GHG emissions have not decreased, but seem to have reached a plateau. The purple stacks represent GHG emissions from residues, which contributed with about 8 million tons in the latest measurements from 2018. According to the same report, the total GHG emissions reached a value of about 90 million tons the year 2007 when the goal of 30% reduction by 2030 was set, which means that the goal is reaching national emission levels of 63 million tons per year.

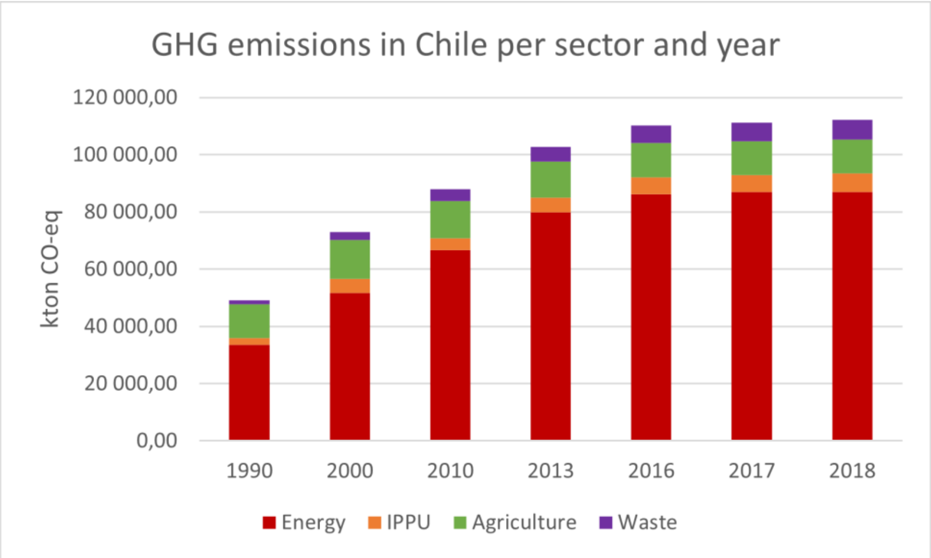

Figure 29. National GHG emissions per sector in Chile 1990-2018. IPPU stands for "Industrial processes and product usage". Note that the scale between the years is not the same throughout the graph. Diagram constructed by the author. (Ministerio del Medio Ambiente 2019)

There is also a series of laws in Chile that is enforcing inclusion of renewable energy in energy generating companies (Ávalos 2021). These laws are commonly known as the ERNC laws, which is an acronym for Non-Conventional Renewable Energy (Spanish: *Energías Renovables No Convencionales*). The first law (Ministerio de Economía 2008), was released in 2008 and states that companies generating over 200 MW must include 5% energy generated from ERNC technologies by 2010. The law was updated in 2013 (Ministerio de Energía 2013), with the same condition as the former, with the only change the inclusion of ERNC being 20% by 2025. If the condition is not met, the company will be fined with a maximum cost of approximately 40 USD per MWh of ERNC not accredited for.

Although the ERNC laws are enforcing implementation of renewable energy, they have also caused issues for smaller renewable producers (Arias 2021). Since the fine of not including renewable energy is set to 40 USD per MWh, it also sets the standard for what price renewable energy producers can expect when they sell their energy to the larger companies. There has been governmental funding for ERNC in Chile through green energy certificates before, but no longer. This limits small renewable energy producers on how much the technology of producing clean energy can sold for and has led to that smaller renewable energy businesses have disappeared during the last years. According to Arias at KDM Empresas, another miscalculation in the law led to that the quota of renewable energy was filled shortly after the law was enforced. Today there is therefore no interest of investment in innovation for new ERNC technologies, since the cost will be high, and no market where their energy could be compatible (Arias 2021).

6 Biogas substrate assessment

In this chapter information about the found sources in the studied municipalities and the region will be presented, in terms of type of substrate, quantity, and (to limited extent), their current waste handling method and associated costs. First the two municipalities El Monte and Providencia and their sources will be presented, followed by general data and a description of an average fictive municipality, which is used later for comparison and discussion.

6.1 *El Monte*

The study in El Monte was done by first collecting data directly from organic waste generating sources and then estimating the total generation from pure flows in an amplified study. This subchapter is therefore divided in two parts, 6.1.1 and 6.1.2.

6.1.1 Studied sources of organic waste

The sources in El Monte that were further studied can be seen in the map in Figure 30 and their yearly organic waste are described in detail below.

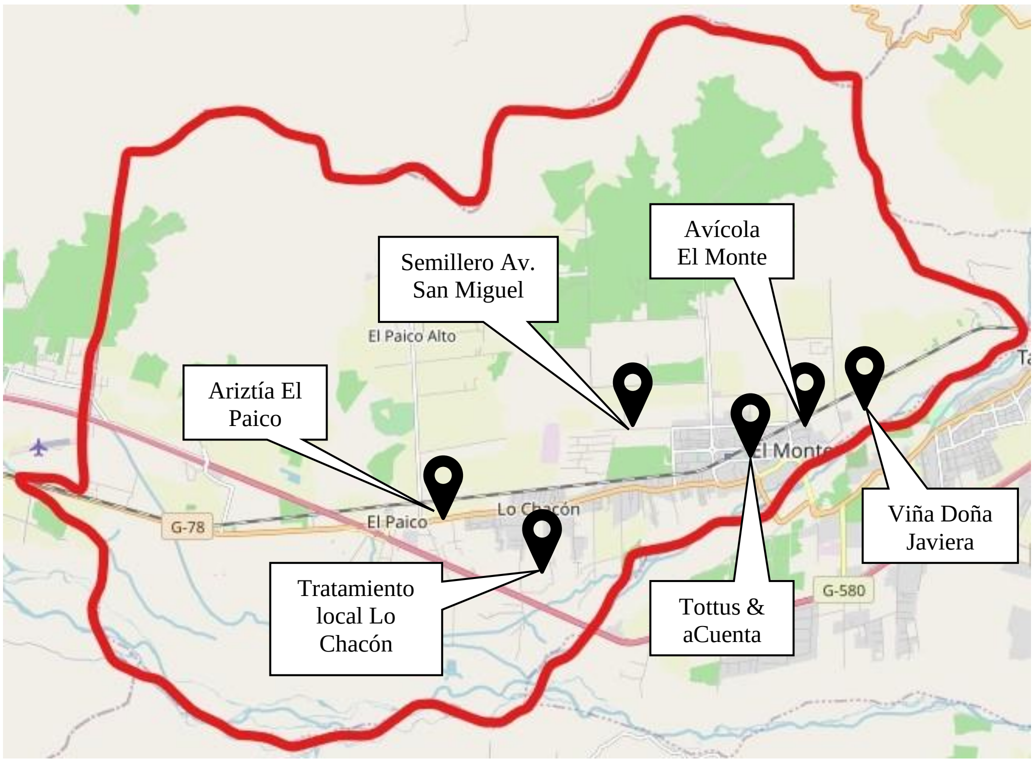

Figure 30. Map over the studied sources in the municipality of El Monte.[5] The locations are approximate.

[5] Map from © OpenStreetMap contributors, used via the Open Database License under CC BY-SA 2.0 https://www.openstreetmap.org/copyright

Seedbed farm - Semillero Avenida San Miguel

Outside the north corner of the central village of El Monte there are several producers of agricultural services. A common sight in Chile is seedbed farms, since the country is among the top ten exporters of seeds in the world (Vicuña Herrera 2013).

At the particular farm investigated in the study, the seeds vary upon demand, but three crops have been more or less consistent over the last few years: cauliflower, bunching onions and lettuce (Sahli Illanes 2021).

Figure 31. The existing compost at the seedbed farm and one of the farm dogs sleeping next to it. (Source: Author)

Today the organic matter of the farm ends up in a simple compost, as seen in Figure 31 including organic household waste and grass from the farmland (Sahli Illanes 2021). The material is left to decompose without further maintenance and is later used as fertilizer on the growing lands together with additional products. In total over the year, 1 200 litres of soil fertilizer (N-P-K 18-18-18%) and 40 litres of foil fertilizers (from algae) is used, which results in a cost of almost 6 700 USD or 5 000 000 Chilean pesos (CLP) per year. The organic waste generation can be seen in Table 5.

Table 5. Organic waste from Semillero Avenida San Miguel in El Monte

Substrate	Wet weight tons/year
Vegetable stalks	8
Straw	3
Mixed food waste (domestic)	1

Vineyard Viña Doña Javiera

The locally famous vineyard of Doña Javiera produces wine from grapes grown on the 665 ha of land that is part of the property, but also from imported grapes from other producers (Armijo 2021). The houses of the vineyard seen in Figure 32 are antique and have survived many decades, and on the lands indigenous trees that are over 250 years old are still growing. Viña Doña Javiera also have great historical value since troops hid at the property during the battle of Rancagua in the 19th century and fled through a kilometre-long tunnel to the church in the centre of El Monte. In fact, the vineyard was declared an historical monument in 1974 due to its involvement in important parts of the national history (Armijo 2021).

Today, the vineyard still writes history by continuing and developing their wine production. 600 tons of grapes are harvested yearly, and 150 tons of waste is generated (Armijo 2021), as seen in Table 6. The harvesting period is February to April and the organic substrates that make up the waste from harvest are grape skin, leaves, sprouts, and small quantities of nondigestible wood from the trunks and canes. Water treatment of the process water also generates sludge that is left to dry during cycles over the year. During pruning in May, the wood is preserved and used as firewood (Armijo 2021).

Figure 32. Courtyard of the vineyard Viña Doña Javiera. (Source: Author).

Most of the organic waste is put in a compost on site, including the harvest residues and sludge but excluding the wood (Armijo 2021). The compost is not sold but used on the local lands or gifted to neighbours. The plantation uses no external energy source other than the sun, but the wine making process requires energy, today provided with electricity.

Table 6. Organic waste from Viña Doña Javiera in El Monte.

Substrate	Wet weight tons/year
Wine making residues	150

Egg and chicken producer – Avícola El Monte

Avícola El Monte is South America's only, and among the world's oldest Hy-Line[6] chicken and egg producer (Ricardo Correa 2021). The waste that they produce mainly consist of chicken manure, also called guano, and to some extent corpses from chickens in the farm. The yearly waste from Avícola El Monte can be seen in see Table 7, where the chicken corpses have been estimated as slaughterhouse waste.

The guano is removed daily from the sheds and transported with a truck to a separate area in the farm where it is spread out in rows outside to take advantage of the sun as heat source (Ricardo Correa 2021). From a starting point the TS of the guano is estimated to 25-30%. It is then mechanically turned and sundried for a period of 20-25 days until it reaches a TS value of approximately 80% at which point it can be sold or used locally as organic fertiliser. This procedure is only performed during the hotter half of the year, and during the winter months

[6] Hy-Line is an international breeding company of chickens specialized in genetic excellence.

the guano is simply not collected. During the year 2020 Avícola El Monte sold slightly over 4 000 tons of fertiliser.

The only costs that are associated with waste handling at the farm is the transportation of the guano from the sheds and mechanical turning (Ricardo Correa 2021). In total it adds up to 4 140 USD (almost 3 000 000 CLP) per month. This cost includes the diesel fuel and devaluation of the truck and machinery, and the monthly salary of the externally hired employee that performs the task.

The chicken corpses that are produced in the farm are composted separately for about 60 days and the remains are later mixed and sold together with the dried guano as fertilizer (Ricardo Correa 2021).

At the farm there are several steps of the production process that requires energy (Ricardo Correa 2021). Liquified petroleum gas (LPG) is used for heating the breeding sheds and electricity is used to control the environment of the egg production, including running technical equipment such as fans, conveyor belts for guano extraction, as well as the feeding and egg collecting systems. The farm also has a set of electrical generators that run on diesel in case of a power outage.

Table 7. Organic waste from Avícola El Monte in El Monte.

Substrate	Wet weight tons/year
Chicken manure (guano)	14 400
Slaughterhouse waste (gastrointestinal)	40

Wastewater treatment plant – Tratamiento local Lo Chacon

In the southwest corner of the municipality El Monte there is a small local treatment plant, see Figure 33, that today obtains domestic water from 70 household in the nearby area (Pino 2021). The treatment plant holds a strong smell and water that leaves the plant seem to still be very rich in nutrients, since the outlet water creek is a growing ground for algae. Regarding the treatment itself it seems to be of low engineering quality, and the responsible for the plant themselves seem to not know what is occurring inside the reactor piscine. As per say, the plant is not well functioning today, and the municipality is looking into other options of how to improve the process for the surrounding environment (Miranda and Mendez 2021).

Figure 33. The existing treatment plant today that consists of one reactor piscine (Source: Author).

One way to complement an improvement of the water treatment that happens onsite could be relieving the outlet water from the high level of nutrients by transferring the sludge to a bioreactor.

The Chilean National Consumer Service (SERNAC 2003) has estimated that the average housing in Chile consists of 5 people, which means that 350 people should be connected to the plant, see Table 8. According to Svenskt Vatten (Finnson and Lind 2020), each person in Sweden connected to a wastewater treatment plant contributes to 100 kWh of energy potential from biogas per year. An assumption was made that the same contribution could be achieved in Chile.

Table 8. Organic waste from wastewater treatment plant Tratamiento local Lo Chacon in El Monte.

Substrate	People connected to plant
Sludge from wastewater treatment	350

Supermarkets - Tottus and aCuenta

There are only two big supermarkets in the municipality of El Monte (Municipalidad de El Monte 2019), that are both stores of larger chains: *Tottus Express* and *Super Bodega aCuenta*. The Register of Emissions and Transfer of Contaminants (RETC) registered 112 and 120 tons of mixed waste from respective stores for the year 2019 (RETC 2019a).

Findings from a study in Ecuador (Alvaro Gualoto and Olives Erazo 2013) showed that organic materials made up 9% of the total waste from supermarkets. The same study found that the organic waste consisted mainly of fruits and vegetables (79%), and to some extent cooked food and meat. By estimation that 9% of the supermarket waste in Chile also is organic material, the two supermarkets would generate 10 tons each of organic residues per year, as specified in Table 9. This number could be reasonable, at least compared to medium-to-large supermarkets in Sweden which produce between 7.2-24 tons of food waste/year (Jensen et al 2011), see Appendix 3.

Table 9. Organic waste from supermarkets in El Monte.

Substrate	Wet weight tons/year
Mixed food waste (supermarkets)	20

Ariztía El Paico

The company Ariztía is a Chilean food producer that owns several nationally acknowledged food brands such as Ariztía, Montina, Cartuja and Rumay (Ruiz 2021). Their journey in food production started 125 years ago with wine production, but today their products are mainly from animal origin, such as meat products from chicken, turkey, beef, cheese, and eggs.

Geographically, the production facilities are spread out from Arica at the north border of Chile to RM, and one of their agro-industrial plants named Ariztía El Paico is found in El

Monte (Ruiz 2021). Here, the production is focused on food items from birds, such as chicken and turkey, and their principal residues is characterised as slaughterhouse waste containing blood, feathers, intestines, and bones. Today almost all waste is valued and sold to a daughter-company, producing animal food. The sludge from the on-site water treatment plant is however not valued and is instead of high cost for the company since it must be removed and treated off-site by an external service.

Due to the size of the Ariztía concern, it was not possible to obtain specific data on the amount nor the cost that are associated with waste handling, since the data is considered sensitive (Ruiz 2021). General data regarding non-harmful waste of organic origin was however found on the open database SINADER (RETC 2019a) with almost 50 000 tons of waste per year and was estimated to be interchangeable with gastrointestinal waste from slaughterhouses, as presented in Table 10.

Worth mentioning is that an agro-industrial plant of this size is not common in the region. Altogether, industries in RM produces 82 091 tons per year of residues of animal origin, divided on 102 producers (RETC 2019a).

Table 10. Organic waste from Ariztía El Paico in El Monte.

Substrate	Wet weight tons/year
Slaughterhouse waste (gastrointestinal)	49 700

6.1.2 Amplified study

The results from 6.1.1 are from specific sources in El Monte. By including similar sources, from found in Table 34 in Appendix 2 and other assumptions presented in this section, a more accurate estimation of the total biogas production potential from the "lowest hanging fruit" in El Monte can be obtained. The findings of the amplified study are therefore presented below, and a summary of the new revised numbers are presented in Table 11 in the next subchapter.

Seedbed-, vegetable- and fruit farms

Estimating number of vegetable farms had to be done in a different way due to lack of data. Most farms in Chile are family owned and vary in size, and the estimation of residues from the agricultural production could instead be done from areal production. A study of fruit production from 2017 estimated 910 ha of the area in the municipality of El Monte used in for fruit production, and on a regional level the production generated 6.9 tons/ha of fruits (Larrañaga and Osores 2017). Worth noting is that this study only focuses on fruit production but could be an indication of usage of land for comestible products.

According to (Sharma et al 2016), fruit production generates about 10-35% waste, and it can be assumed to be similar for vegetable production. To include nondigestible parts such as substrates with high content of cellulose, an estimation of waste generation of 20% from the production was done.

Vineyards

There are two vineyards of commercial scale in El Monte. Due to lack of other data, they are estimated to generate the same amount of organic waste.

Egg and chicken producers

Avícola El Monte is among the larger producers focused on products from chicken breeding in the municipality. Most other producers are small, family-owned companies. However, after researching the area together with contacts of the municipality (Miranda and Mendez 2021), there seem to be one other company that has a production facility similar in size to Avícola El Monte. For the amplified study of pure substrates, two egg and chicken producers are therefore accounted for.

Wastewater treatment plants

There are today at least two other wastewater treatment plants than Tratamiento local El Chacon in El Monte, both owned by the Chilean wastewater treatment company, Aguas Andinas (RETC 2019a). They generate together about 1 900 tons wet weight of sludge per year, which today is transported to landfills in other parts of the region (97 % is transported 22 km to El Trebal and 3% is transported 87 km to Tiltil). Since the former wastewater treatment plant is not presented in wet weight sludge per year as the two presented in this paragraph, their data is separated in Table 11.

Supermarkets and fruit and vegetable markets

There are no other large supermarkets in the municipality than the two already mentioned in the study and no data was found on waste from local fruit and vegetable markets.

Slaughterhouses

There are no other known large-scale slaughterhouses in the municipality than Ariztía El Paico and the amplified study does therefore not add any new information on waste from slaughterhouses.

6.1.3 Summary of sources in El Monte

A summary of the findings in the amplified study in El Monte are presented in Table 11 below. The information of substrate type and quantity is what was used in the model to calculate the biogas and energy potential and could represent the “lowest hanging fruit” of biogas production in El Monte.

Table 11. Summary of sources in amplified study in El Monte.

Source	Amount	Wet weight tons/year
Seedbed-, vegetable- and fruit farms	Unknown (910 ha)	1 300
Vineyards	2	300
Egg and chicken producers	2	28 900

Water treatment plants	2 (+1)	1 900 (+350 people)
Supermarkets	2	20
Slaughterhouses	1	49 700

6.2 Providencia

Since Providencia is a central municipality with a high density of inhabitants, the possibilities for industries that generate large flows of organic waste are limited (Valenzuela Hernándes et al 2021). Another common source of organic waste in Chile are fruit- and vegetable markets, but in Providencia they are small to both the number and size. Moreover, the waste generated from markets is not handled by the municipality but instead gathered and used internally by the market-sellers as animal food.

The study of large flows of organic waste in the municipality of Providencia instead focused on three types of sources:

1) Supermarkets that have a large section of fruits, vegetables, bread, and meat as well as large restaurant chains
2) Housing complexes where the municipality already have high interest in implementing waste separation at the origin.
3) Waste from communal parks and green areas.

The data received in Providencia was not obtained directly from the sources and is of more general character than in El Monte. The study could therefore be considered on a general municipal level directly to be compared to the amplified study in El Monte.

Supermarkets and restaurant chains

In Providencia, there are several supermarkets that sell fresh fruits, vegetables, bread, meat, and dairy products (RETC 2019b). The whole list of found supermarkets in the municipality can be seen in Appendix 2. The supermarkets and restaurant chains that generated over 100 tons total waste yearly were selected for the study and are listed in Table 12.

The estimation of organic waste from supermarkets (9%) was made as with the supermarkets in El Monte and is based on the study of waste composition from supermarkets in Ecuador (Alvaro Gualoto and Olives Erazo 2013).

Table 12. Large supermarkets in Providencia and estimated organic waste per year.

Name and location	Total amount of waste (tons/year)	Estimated quantity of organic waste (tons/year)
Supermercado Jumbo | Av. Andrés Bello 2465	2 390	220
Supermercado Lider | Av. Pedro de Valdivia 1885	490	40

Supermercado Lider | Las Camelias 2875	370	30
Supermercado Lider | Rancagua 0180	320	30
Supermercado Lider | Manuel Montt 80	270	20
Supermercado Lider | Av. Nva. Providencia 2249	210	20
Supermercado Lider | Santa Isabel 170	210	20
Supermercado Tottus | Av. Bilbao 451	140	10
Supermercado Unimarc | Av. Manuel Montt 1097	120	10

Providencia is also dense in restaurants, many that are of international chains. However, it is difficult to find data on the amount of food wasted from private owned companies since the information can be considered sensitive to the brand. Data on total waste generated from one restaurant chain was found and is presented in Table 13 below. A study on composition of waste generated from restaurants in Italy (Tatàno et al 2017) suggests that 28.2% is of organic character, which can be assumed to be similar to the organic waste fraction from restaurants in Chile.

Table 13. Restaurant chains and waste generated in Providencia.

Number of restaurants	Restaurant chain	Total amount of waste (tons/year)	Estimated quantity of organic waste (tons/year)
5	McDonald’s	110	30

Housing complexes

According to representatives of the municipality (Valenzuela Hernándes et al 2021), there are three housing complexes where there is a particularly high interest in improving the existing waste management system. These three complexes can be seen on the map in Figure 34.

Figure 34. Map over Providencia divided into neighbourhoods, with three housing complexes marked out. Used with permission of the copyright owner Cristian Bravo Riquelme.

The main reason why these three complexes are of high interest is that their waste generation is overwhelming due to high population density (Valenzuela Hernándes et al 2021). The garbage truck sometimes needs to pass twice a day to pick up waste to not overflow the existing containers. The number of inhabitants per complex and the daily organic waste generation per complex is presented in Table 14.

Table 14. Housing complexes in Providencia that are interesting for this study and their waste generation.

	Name	Neighbourhood according to map	Number of inhabitants	Daily domestic organic waste generation (kg)
A	Comunidad Sector 2 Unidad Vecinal Providencia	3	580	370
B	Comunidad Sector 5 Unidad Vecinal Providencia	3	660	430
C	Comunidad Parque Inés de Suárez	7	790	500

The organic household waste makes up about half of the total amount of waste, which means that for example housing complex C itself generates a ton of mixed waste on daily basis. On the scale of a year, the housing complexes A-C generate 470 tons organic household waste that could be used as substrate in biogas production.

Parks and green areas

Although the abundance of tall buildings, Providencia is among the greenest municipalities of central Santiago (Municipalidad de Providencia 2021). This is good in many ways, but also results in that each autumn, there is an overflow of dead leaves that needs to be handled by the municipality. These leaves could serve as a substrate of anaerobic digestion.

A study was made 2017 at the local University of Heidelberg in Chile (Hermosilla and Tapia 2017), where the foliage of the common tree species *Platanus Orientalis* was studied. The study took place in Providencia and determined the location and quantity of leaves that needed to be collected each year. Over 4 000 trees of *Platanus Orientalis* were counted in the study and the trees (excluding very small trees) generated approximately 40 tons of biomass per year, as seen in Table 15.

Table 15. Waste generated from trees planted in Providencia.

Substrate	Wet weight tons/year
Leaves from *Platanus Orientalis*	40

6.2.1 Summary of sources in Providencia

A summary of the findings in Providencia are presented in Table 16 below. The information of substrate type and quantity was used in the model to calculate the biogas and energy potential and could represent the "lowest hanging fruit" of biogas production in Providencia.

Table 16. Sources of organic waste, their substrate type and quantity generated in Providencia.

Source	Type of substrate	Wet weight tons/year
Supermarkets	Mixed food waste (supermarkets)	410
Restaurant chains	Mixed food waste (restaurants)	30
Housing complexes	Mixed food waste (domestic)	470
Parks and green areas	Plant and garden waste	40

6.3 General data

To include other sources than those found in the municipal studies in the case studies and the discussion, general data of organic waste from open-air markets and mixed municipal waste is presented in this subchapter.

6.3.1 Open-air markets in RM

A source of organic waste that is common in Chile and potentially could be suitable for anaerobic digestion are open-air markets (Spanish: *ferias libres*), where the Chileans commonly buy their fruits and vegetables directly from the producers. Most of these take place once or twice per week at specific locations, but some larger markets hold permanent stands and that are open every day. The two largest permanent markets in RM are *La Vega Central Market* (in the municipality Recoleta) and *Feria Lo Valledor* (in the municipality Pedro Aguirre Cerda) which produce 500 and 900 tons of organic waste per month, respectively (Norambuena 2009). The organic waste can be assumed to consist of fruit and vegetable residues and the total weight of the organic waste from both these two markets is found in Table 17.

According to a study regarding energy potential from organic residues performed by the municipality of Recoleta (Pendola 2017), the total number of open-air markets in RM is 455, which in total generate 70 000 tons of organic waste per year. This corresponds to an average generation of 154 tons organic waste yearly per market. Using the statistics from (INE 2019a) that 8 million people live in RM, the average population per market is 17 600 people. Organic waste from all open-air market in RM, is also presented in Table 17.

Table 17. Open-air markets in RM and their waste generation.

Feria libre	Organic waste tons/year
La Vega	6 000
Lo Valledor	10 800
All 455 in RM	70 000

6.3.2 Organic matter in mixed municipal waste

In mixed municipal waste in Chile, or as referred to earlier, SNDW, 58% is organic matter (Ministerio de Medio Ambiente 2020). If an implementation of organic waste separation in Chile would become reality, the organic household waste could contribute to the biogas and energy potential. Table 18 presents the amount of organic waste found in what is today classified as SNDW in the studied municipalities, in RM as well as in Chile.

Table 18. Organic waste from municipal waste projections year 2021 (Arias 2021). **58% of the found projections.*

Area	Organic waste tons/year*
El Monte	7 100
Providencia	39 700
RM (all 52 municipalities)	1 922 000
Chile	4 060 000

6.3.3 Geographical data

A short summary of geographical information of the studied municipalities as well as the Metropolitan Region as a whole is presented in Table 19 below.

*Table 19. The municipalities selected for the study and RM, their population and ruralness. *Seen to number of inhabitants per ruralness level in RM.*

Area (name)	Number of inhabitants	Area (km^2)	Ruralness (SEREMI 2019)
El Monte	36 000	118	Semi-rural
Providencia	150 000	14	Urban
RM	8 000 000	15 403	Mixed (Mainly semi-urban*)

6.4 Description of average fictive municipality

This subchapter aims to present a description of an average municipality in RM and is to be considered as fictive. The average numbers and conditions in the fictive municipality is derived from data gathered and presented previously in Chapter 6. The number of restaurants has not been taken into consideration in the fictive typical municipality, due to the low quantity and uncertanty of the data found about restaurants in the studied municipalities and in the region.

The assumptions and calculations, as well as on which basis the data has been normalised to reach the numbers in this subchapter can be found in Appendix 3. The data in Table 20 describes the conditions of the average fictive municipality.

*Table 20. Data assumed for the fictive municipality. *Supermarkets that generate 100 tons waste or more per year.*

Data	Quantity
Population	153 846
Number of households	30 769
Rurality	Semi-urban
Area	296 km^2
Urban area	50%
Farmland area	11.41 km^2
Number of open-air markets	9
Number of supermarkets*	9
Number of vineyards	3

Number of egg and chicken producers	3
Number of normal-scale slaughterhouses	2

To illustrate the size and possible location of the fictive municipality, a 296 km^2 square has been drawn out of the map in Figure 35. The square is located in an area which is classified as semi-urban.

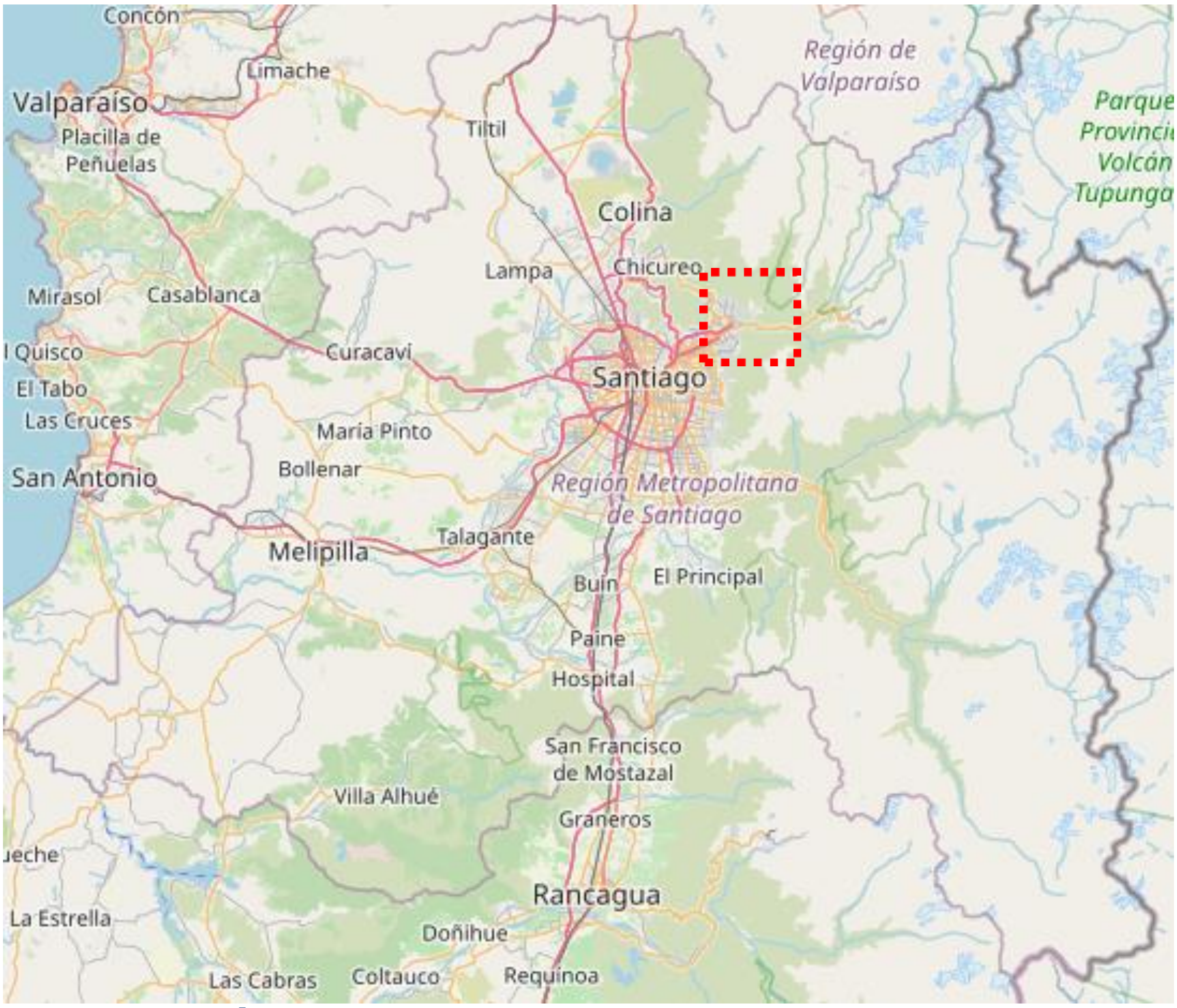

Figure 35. Map over RM [7] with the fictive area marked out. The area is scaled and positioned according to the data in Table 20. Edited by the author.

By using the data in Table 20 combined with data from the studied municipalities and general data, waste flows could be calculated. The calculations are found in Appendix 3. The sources and the quantity of organic waste that make up the waste flows in the average fictive municipality are presented in Table 21 below.

[7] Map from © OpenStreetMap contributors, used via the Open Database License under CC BY-SA 2.0 https://www.openstreetmap.org/copyright

Table 21. Organic waste sources of the typical fictive municipality.

Source	Organic waste tons/year
Municipal waste	370 000
Open-air markets	1 400
Supermarkets	350
Park and green areas	460
Wastewater treatment	- (Different basis of calculation)
Farmland	1 600
Vineyards	450
Egg and chicken producers	43 300
Slaughterhouses	3 200

7 Results

In this chapter, the results in terms of biogas and energy potential will be presented. The results from the two studied municipalities El Monte and Providencia, followed by the fictive municipality will first be demonstrated through tables and diagrams in three separate case studies. A comparison on municipal level between the three cases will then be made, and lastly, the potential on a regional scale will be presented.

The two selected municipalities, El Monte and Providencia, both have very specific conditions, and their results cannot not represent the region as a whole. The average fictive municipality that was described in chapter 6.4 is however normalised to average values of for example population and area, and is therefore more representative of regional conditions, on a municipal level. Three case studies describing the biogas potential and energy potential of El Monte, Providencia and the fictive municipality will follow in this chapter. When reaching the comparison between the cases, in subchapter 7.4, it is important to remember that the study of the two existing municipalities only has included real sources and data, while the fictive municipality is expanded to include generalised, as well as estimated data. Due to these differences, the result of the comparison cannot be considered absolute, and only serves as a basis of discussion.

7.1 Case study 1 – El Monte

7.1.1 Pure organic waste flows in El Monte

The study of pure organic waste flows in El Monte was as done by first collecting data from specific sources and then amplifying the study to include similar organic waste sources in the municipality. The contribution to the biogas and energy potential per source category is presented in Table 22. The sources add up to a biogas potential of over 6 900 000 Nm^3 per year, corresponding to an energy potential of approximately 42 GWh.

Table 22. Biogas and energy potential in El Monte.

Source	Nm^3 biogas per year	GWh per year
Seedbed-, vegetable- and fruit farms	119 300	1
Vineyards	31 500	0
Egg and chicken producers	2 152 800	12
Wastewater treatment plants	33 900	0
Supermarkets	2 500	0

Slaughterhouses	4 577 000	29
Total	**6 917 000**	**42**

The biogas potential from both the studied sources and the amplified study can be seen in Figure 36. By performing the amplification compared to only using the found sources, the biogas potential increased with approximately 22%. As seen in Figure 36, slaughterhouses are dominant in the contribution to the potential, followed by egg and chicken producers and farmland.

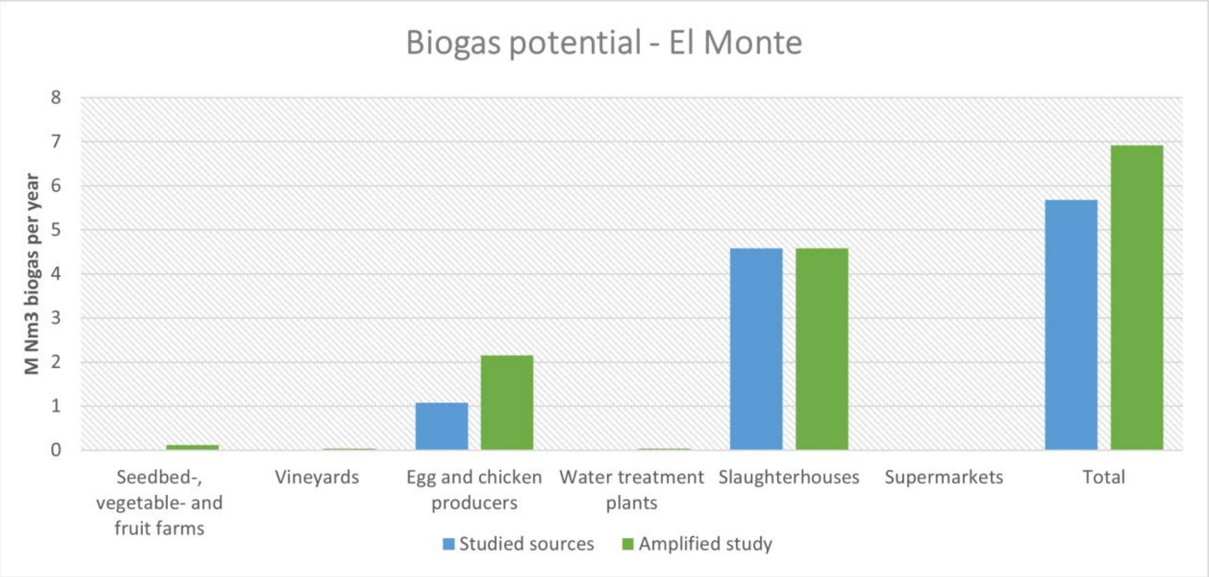

Figure 36. The biogas potential in million Nm^3 per year in El Monte of the studied sources and the amplified study.

The energy potential from the amplified study in El Monte is as mentioned 42 GWh per year, and the division per source category can be seen in Figure 37.

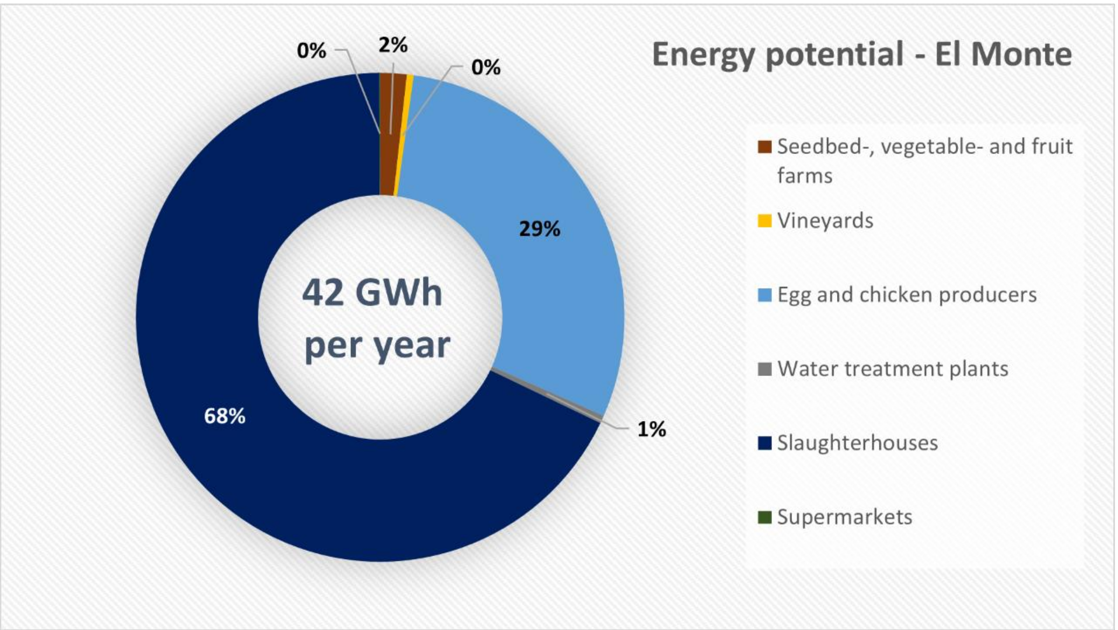

Figure 37. Energy potential from the amplified study in El Monte.

7.1.2 Organic waste in mixed flows in El Monte

To obtain a futuristic perspective of the biogas potential, organic waste today found in mixed municipal waste in El Monte was also added, as seen in the subchapter 6.3 of general data. The new potential can be seen in Table 23, and is as seen increased by 21%.

Table 23. Organic waste from mixed flows in El Monte and their contribution to the total potential.

Source	Substrate	Biogas potential Nm^3/year	Energy potential GWh per year
Municipal organic waste – El Monte	Mixed food waste (domestic)	1 458 000	9
New total potential El Monte		**8 375 000**	**51**
Change when adding mixed flows		+21%	+21%

7.2 *Case study 2 – Providencia*

7.2.1 Pure organic waste flows in Providencia

The waste from the studied sources in Providencia has a biogas potential of almost 160 000 Nm^3 per year which corresponds to an energy potential of almost 1 GWh per year, as presented in Table 24.

Table 24. Potential of biogas, effect and energy from substrate flows in Providencia.

Source	Nm^3 biogas per year	GWh per year
Supermarkets	48 700	0.3
Restaurant chains	5 800	0
Housing complexes	95 400	0.6
Parks and green areas	6 500	0
Total	**156 400**	**1**

The biogas potential is also illustrated in Figure 38 below. As can be seen, the organic waste from the three studied housing complexes are the largest contributors to the potential, followed by supermarkets.

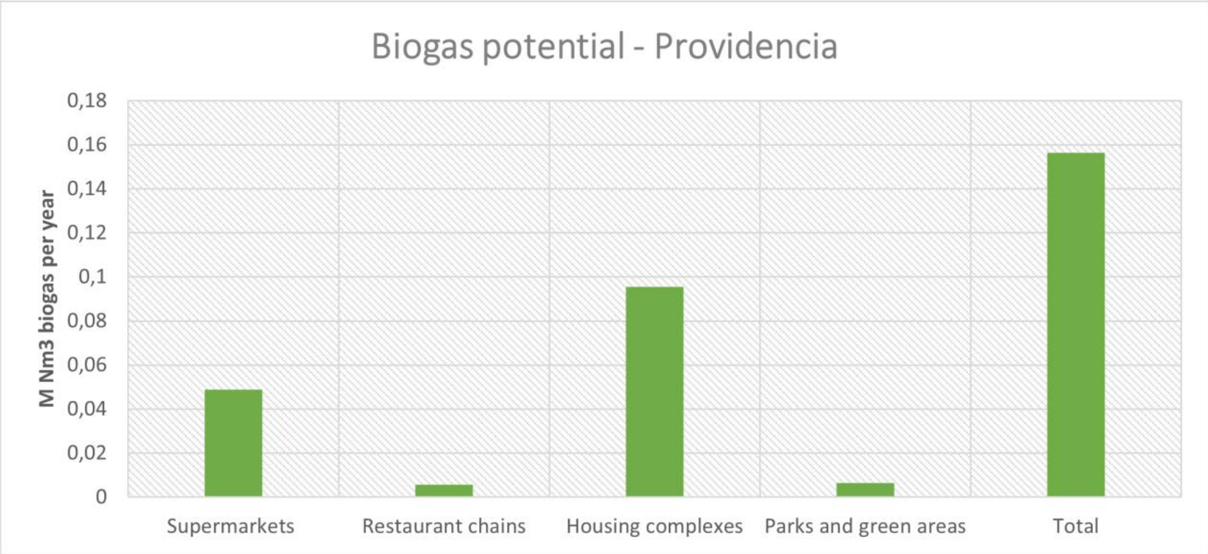

Figure 38. Biogas potential in million Nm³ per year in Providencia divided per source category.

The energy potential from the found sources in Providencia is approximately 1 GWh per year. The contribution to the energy potential per source category in Providencia can be seen in Figure 39.

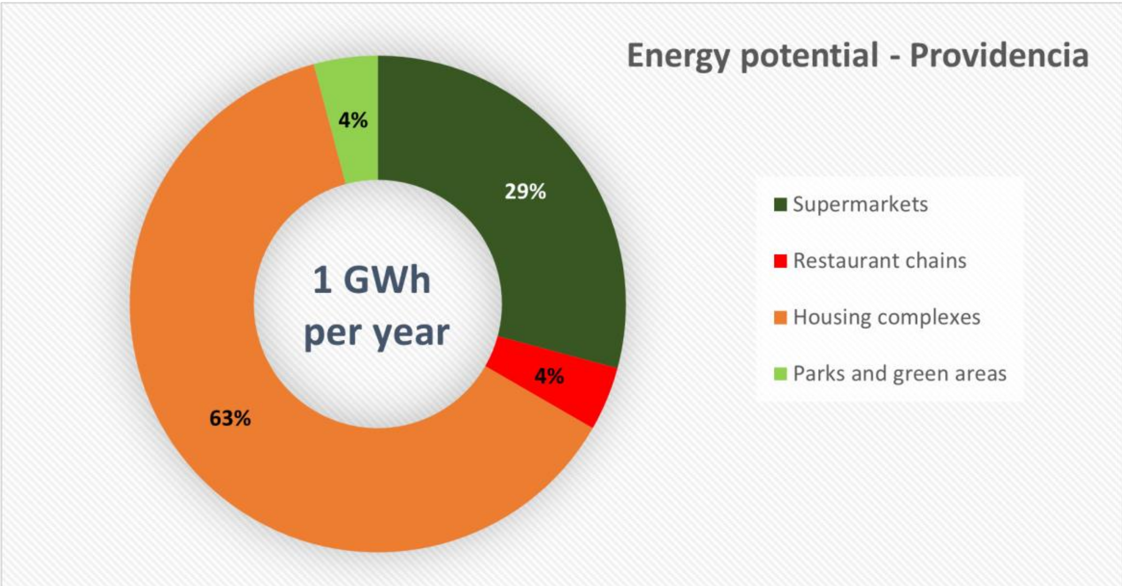

Figure 39. Energy potential per source category in Providencia

7.2.2 Organic waste in mixed flows in Providencia

By adding the organic waste found in mixed municipal waste in Providencia, the potential changes drastically. As can be seen in Table 25, the biogas potential expressed in Nm^3/year and GWh/year increases with over 5 000% when adding the municipal organic waste found in mixed flows.

Table 25. Organic waste from mixed waste flows in Providencia and its impact on the biogas potential.

Source	Substrate	Biogas potential Nm^3/year	Energy potential GWh per year
Municipal organic waste – Providencia	Mixed food waste (domestic	8 095 400	51
New total potential Providencia		**8 251 800**	**52**
Change when adding mixed flows		+5 280%	+5 200%

7.3 Case study 3 – Fictive municipality

When studying the potentials from El Monte and Providencia, as presented in subchapters 7.1-7.2, it is inevitable to notice the difference between the two selected municipalities, with energy potentials of 42 GWh and 1 GWh respectively. The difference made the author draw the conclusion that it is impossible to know the representativeness of the municipalities to the region as a whole, without performing an additional study. The decision to create a fictive typical municipality from average data was therefore taken, and the description of the fictive municipality has already been presented in subchapter 6.4.

The case study of the fictive municipality included all sources of organic waste on municipal level, including mixed flows. In this subchapter, the biogas and energy potential from sources that have not already been covered in subchapters 7.1-7.2 are therefore first presented, followed by the potential in the average fictive municipality.

7.3.1 Biogas and energy potential from general data

General data of organic waste from open-air markets and mixed municipal waste was presented in subchapter 6.3. The corresponding biogas and energy potential of the sources are presented in Table 26. The biogas potential for domestic food waste for El Monte and Providencia has already been presented in previous subchapters.

Table 26. Biogas and energy potential from open-air markets and municipal organic waste.

Source	Substrate	Biogas potential Nm^3/year	Energy potential GWh per year
Open-air market La Vega	Fruit and vegetable residues	569 700	4
Open-air market Lo Valledor	Fruit and vegetable residues	1 025 500	6
Open-air markets All 455 in RM	Fruit and vegetable residues	6 646 500	41
Municipal organic waste – El Monte	Mixed food waste (domestic)	1 458 000	9
Municipal organic waste – Providencia	Mixed food waste (domestic	8 095 400	51

Municipal organic waste – RM	Mixed food waste (domestic	392 020 800	2 462
Municipal organic waste – Chile	Mixed food waste (domestic	827 996 400	5 200

7.3.2 Biogas and energy potential in the average fictive municipality

The categories of organic waste flows in the fictive municipality are presented in subchapter 6.4 including all calculations and estimations that have been made to reach the average conditions. The fictive municipality representing an average municipality in RM has a biogas potential of almost 13 900 000 Nm^3 per year corresponding to an energy potential of approximately 86 GWh, as seen in Table 27.

Table 27. Organic waste sources of the fictive municipality and the potential in Nm^3 biogas and GWh energy per year.

Source	Biogas potential Nm^3/year	Energy potential GWh per year
Municipal waste	7 538 800	47
Open-air markets	131 600	1
Supermarkets	42 100	0
Park and green areas	68 300	0
Wastewater treatment	2 374 200	15
Farmland	149 500	1
Vineyards	47 300	0
Egg and chicken producers	3 229 200	19
Slaughterhouses	290 400	2
Total	**13 871 600**	**86**

The division of biogas potential in million Nm^3 per year between the different sources can be seen in Figure 40, as well as the total biogas potential. The main contributors are municipal organic waste (54%), egg and chicken producers (23%) and wastewater treatment plants (17%).

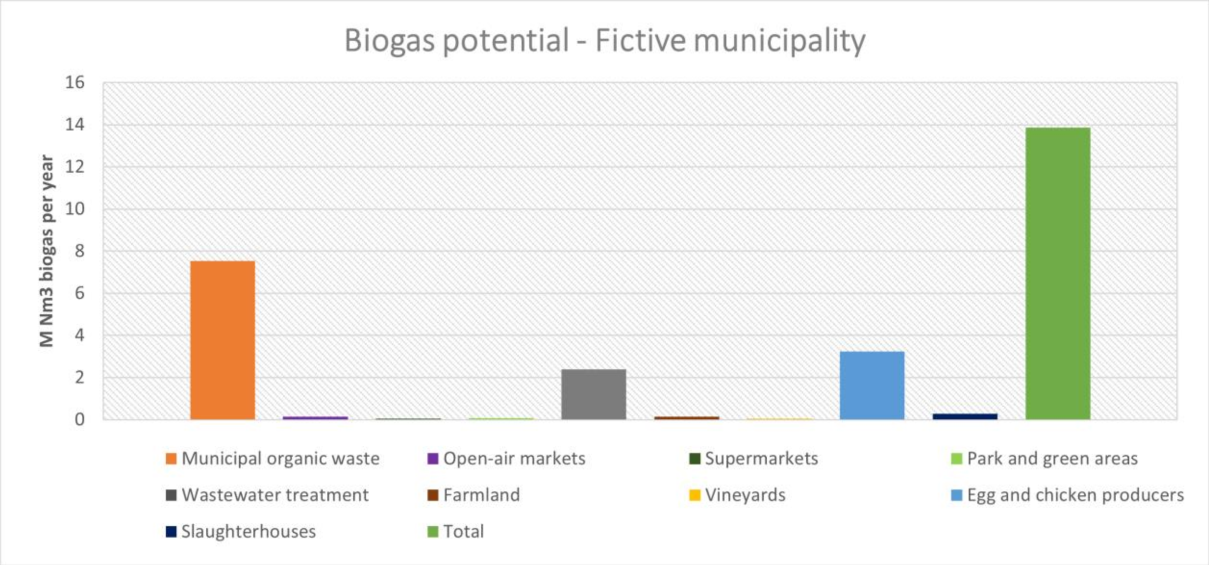

Figure 40. Biogas potential in million Nm^3 from organic waste sources in the average fictive municipality.

The energy potential in the fictive municipality is 86 GWh per year and the division of the potential per source is presented in Figure 41. Worth noting is that over half of the potential coming from municipal organic waste, that today is found in mixed flows.

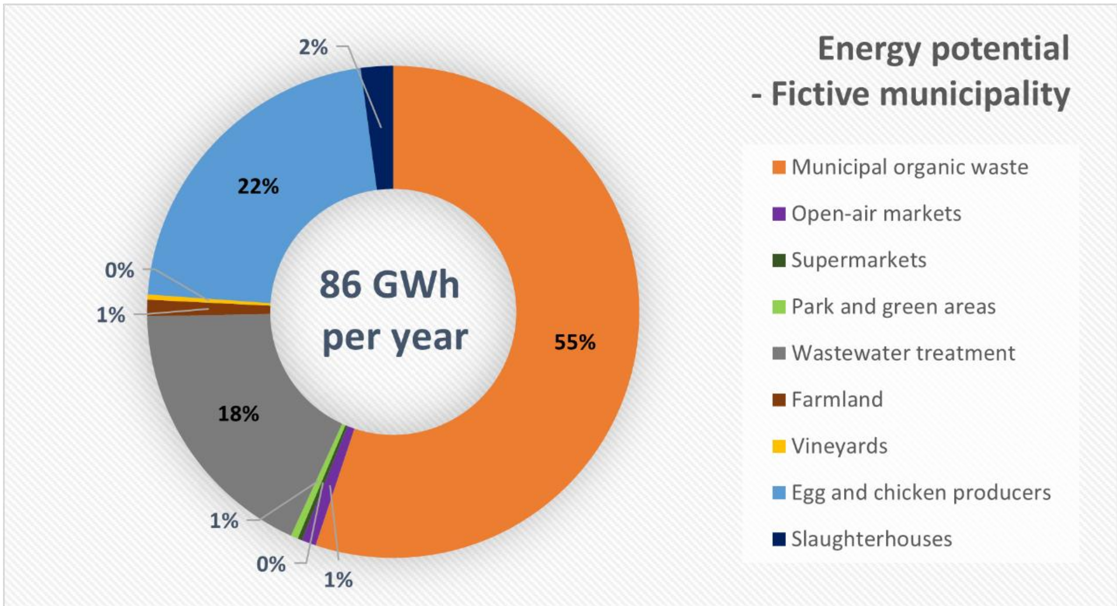

Figure 41. Energy potential from organic waste sources in the fictive municipality.

7.4 Comparison on municipal level

To ground for the discussion, a comparison on municipal level was made between the results from the three case studies. It is however important to remember that the studies of El Monte and Providencia have their basis in specific sources and are therefore not as inclusive as the fictive municipality. In the comparison food waste found in mixed municipal waste has been included for all three municipalities. Another important difference is that although some the sources are calculated for in the fictive municipality, they may not even appear, or even exist, in every municipality of the region. It may also be that some of the sources exist in the studied municipalities, but the data was not found during the study. The comparison between the two existing municipalities and the fictive municipality should therefore not be handled as an actual result of the potentials, but more as a basis for discussion.

A comparison of the geographical conditions for the three municipalities can be seen in the diagram in Figure 42. The scales of the axis in normalised according to the following criteria:

- Inhabitants – compared to the greatest number of inhabitants of the most populated of the three municipalities: 153 800 people in the fictive municipality.
- Area – compared to the area of the largest of the three municipalities: 300 km^2 in the fictive municipality.
- Ruralness – compared to the rurality of the most rural of the three municipalities, with the scale urban to rural (1-4): semi-rural (3) in El Monte.

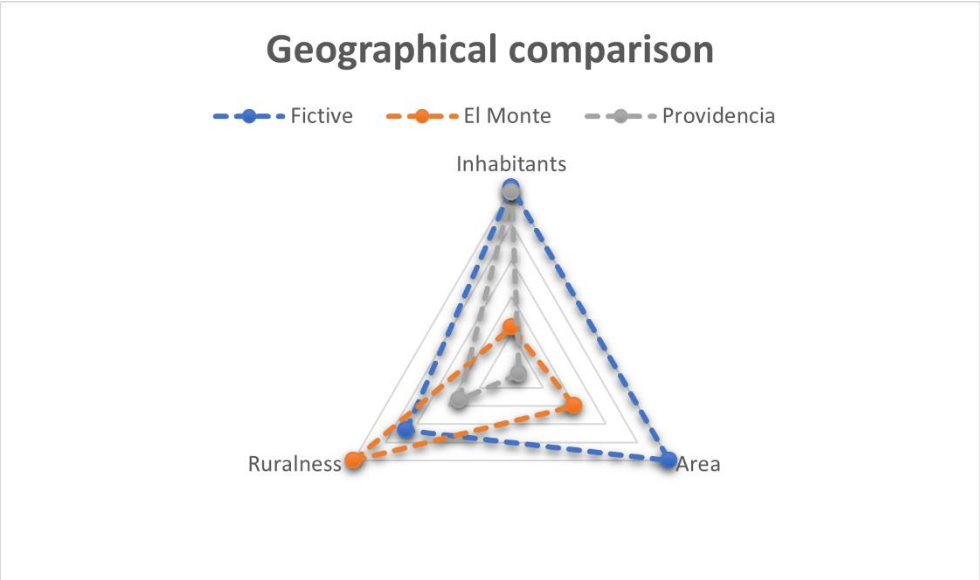

Figure 42. Comparison of geographical conditions between the fictive municipality, El Monte and Providencia.

The comparison of biogas potential per source of the fictive municipality, El Monte and Providencia is presented in Figure 43 below. To make a better comparison between the two real municipalities and the fictive municipality, mixed municipal waste was included for both El Monte and Providencia.

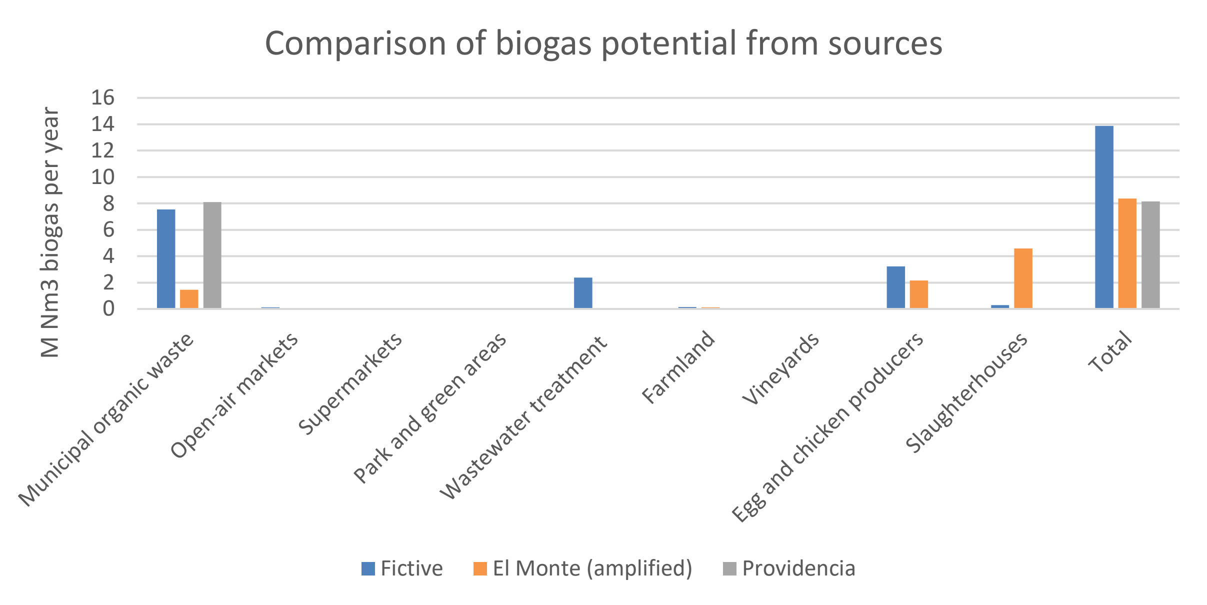

Figure 43. A comparison between the studied municipalities and the fictive municipality in terms of biogas potential in million Nm^3 from different sources.

As seen in Figure 43, the fictive municipality has a considerable higher biogas potential than the studied municipalities. The contribution from municipal waste is almost the same in the fictive municipality as in Providencia, which partly can be explained by similar number of inhabitants. Worth noting is that when taking the today mixed municipal waste into consideration for the biogas potential, El Monte and Providencia have almost the same total potential, where the agricultural industries of slaughterhouses and egg and chicken producers in El Monte, is weighed up by the high amount of organic municipal waste from the dense population in Providencia. It is also interesting to see the high contribution of slaughterhouses in El Monte, compared to the average value in the fictive municipality, as well as the high contribution from wastewater treatment only in the fictive municipality.

The potential depending on source has been presented several times, and to get another point of comparison, the energy potential depending on the energy need from domestic gas and electricity consumption in the three municipalities is now presented. An average home in Chile uses in total 2 100 kWh energy from gas, and 2 520 kWh electricity (Ministerio de Energía 2019a), as seen in subchapter 5.2. There are on average 5 people per household in Chile (SERNAC 2003). Using this information, together with population sizes, it is possible to compare the energy potential with the energy need from housing in each municipality, to estimate how much of the energy need could be covered with the biogas potential found in the study. The energy from domestic gas use covered from the full biogas potential is presented in Figure 44, and the energy from domestic electricity use covered by half of the potential is presented in Figure 45. The reason for using 50% of the biogas potential is the expected energy loss of conversion, as explained in subchapter 4.5.

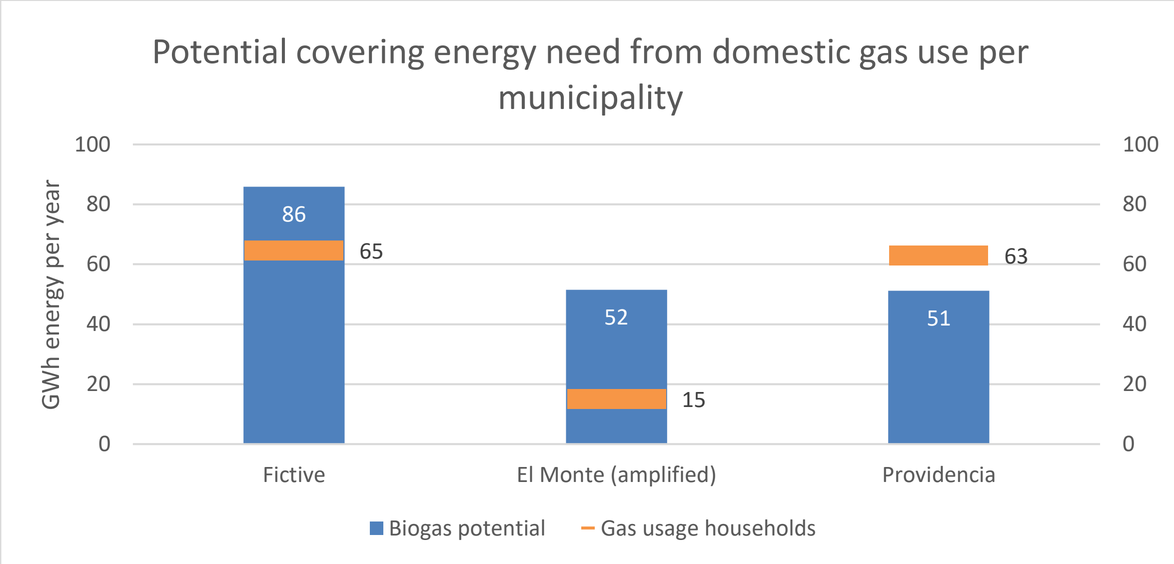

Figure 44. Total energy potentials in the average fictive municipality and the two studied municipalities, with domestic gas use in each municipality marked out with an orange line.

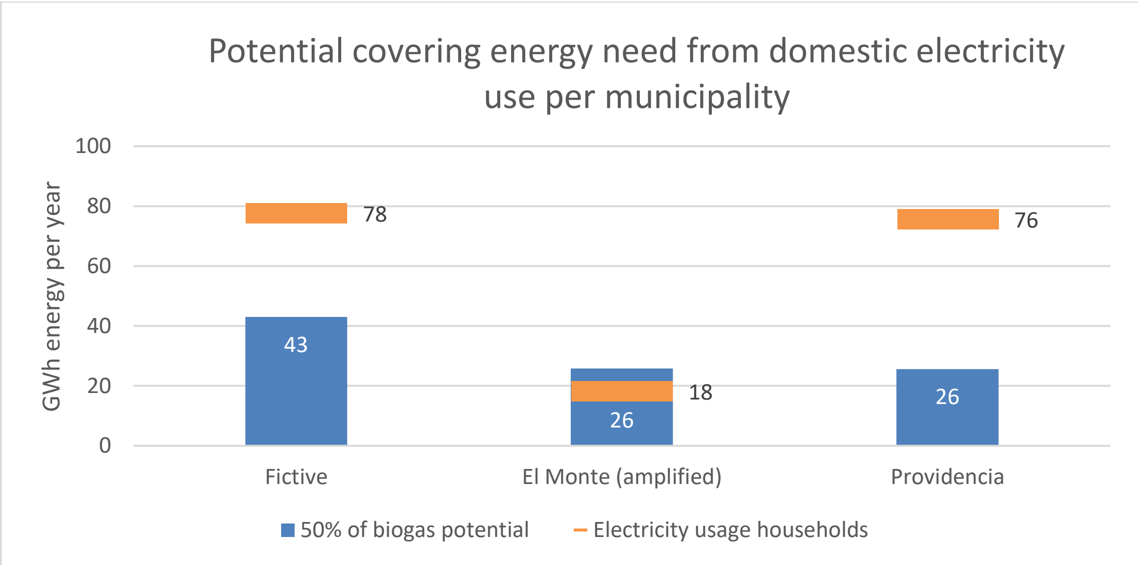

Figure 45. Half of the energy potentials in the municipalities, with energy demand from domestic electricity use in each municipality marked out with an orange line.

7.5 Biogas potential on regional level

The fictive municipality is representing an average municipality in RM, which means that the potential in the region can be estimated as 52 fictive municipalities. By doing so, the biogas potential in the Metropolitan Region on a yearly basis becomes 720 million Nm^3 and the energy potential 4 500 GWh.

One use of the biogas potential could be generation of electricity. The total electricity production in Chile 2020 was approximately 78 000 GWh (Generadoras de Chile 2021), as seen in subchapter 5.2.1. If the energy potential from biogas production in RM would be converted to electricity 50% energy losses, the generation would correspond to 3% of the current national electricity production. It may seem like a small part but compared to wind and solar power generation 2020 covering about 10% and 16% of the national production respectively, it is important to remember that the 3% of electricity could be generated from biogas in RM alone. On a national level the biogas potential could possibly be the double, since almost half the population lives in RM, but due to the shape of the country and the fact that the population do not live as densely outside of the borders of the Metropolitan Region, the accessibility of organic waste in other regions might not be as easy. However, the found potential of 3% itself speaks for that if a regional system of biogas production in RM would be implemented with the purpose of converting it to electricity, the electricity contribution could be considered of importance even on a national level.

In the end of the last subchapter, 7.4, the biogas potential was put in context of the domestic energy consumption. Figure 44 showed how much of the electricity consumption could be covered if the potential biogas were converted to electricity with 50% efficiency. Since the fictive municipality was created from average data, the comparison is also valid on a regional level. As seen in the stack of the fictive municipality, the biogas potential could therefore cover 55% of the domestic electricity need in the region. El Monte, as the only example, has enough potential to cover all the domestic electricity consumption of the inhabitants of the municipality, and Providencia only cover 34% of the need.

Due to the high energy losses associated with electricity generation, the biogas might fit better in other applications, for example as an alternative to natural gas.

Subchapter 4.5 explained that biogas can be upgraded to biomethane with low conversion losses to be used as a substitute to natural gas, which today dominates the Chilean gas market, as mentioned in subchapter 5.2.3. Biomethane could thereby be compatible on the gas market, for application where a purer product is needed, for example as cooking gas distributed in grids to households, or in industrial applications. The gas need in households on municipal level was seen in the previous subchapter in Figure 44, and the stack for the fictive municipality could be used as reference for the domestic gas use that could be covered by the biogas potential, also on a regional level. As seen in the stack, the biogas potential found in the study would be upgraded to biomethane without any energy losses, it could cover over 100% of the domestic use of gas in all the region. However, the logistic challenge of becoming an actor on the gas market remains, as explained in subchapter 5.2.3.

Another alternative would be to use the biomethane as vehicle gas. In subchapter 4.5, the yearly energy needs for a city bus and garbage truck that run on biogas was presented as 370 MWh and 120 MWh, respectively. 4 500 GWh would therefore be enough to run 12 200 buses or 37 500 garbage trucks. As seen in subchapter 5.2.2. RM has about 18 000 buses for public transport and 48 000 trucks in the region. Assuming that all buses and trucks in the region would have the mentioned energy need, the buses in the region require 6 700 GWh per year and the trucks 5 800 GWh per year. The biogas potential could therefore cover 67% of the energy need from buses that run in public transport in RM, or 78% of the energy need of trucks in the region.

7.6 Potential effects on climate impact

If the buses or trucks today are running on diesel, as Scania claimed that most of their trucks do today, switching to biogas would lower the greenhouse gas emissions, according to the data presented of emissions per fuel type in subchapter 4.5.

The difference of emissions between biomethane from waste and fossil diesel can be calculated to 81.4 g CO_2-eq/MJ. If the buses or trucks would maintain the same energetic need no matter the fuel type, it can also be estimated that the 4 500 GWh could be multiplied with the difference of climate impact per fuel to get the reduction of greenhouse gas emissions from making use of the potential. As seen in Table 28, changing the fuel would reduce greenhouse gas emissions by 1.3 million tons CO_2-eq per year (for detailed calculation see Appendix 3).

According to Figure 29 in subchapter 5.2.4, residues also cause emissions in Chile. In 2018, the national emissions from residues were about 8 million tons CO_2-eq. By estimating that 25% of the national residual GHG emissions come from organic waste in RM (since about 50% of the population live in the region and 50% of the waste consist of organic matter) the annual emissions from organic waste in RM is about 2 million tons CO_2-eq. If these could be lowered by half from the removal of organic matter in the mixed waste, another 1 million tons CO_2-eq could be cut, as seen in Table 28.

In total, the regional biogas potential could therefore contribute to lowering the greenhouse gas emissions in Chile with at least 2 million tons per year, corresponding to 2% of the 110 million tons emitted in 2018. By amplifying the system to a national level, using anaerobic digestion as a treatment method for organic waste could therefore contribute remarkably to lower the nation's greenhouse gas emissions.

Table 28. Effects on climate impact from the biogas potential.

Source	Reduced climate impact (tons CO_2-eq/year)
Changing fuel from fossil diesel to biomethane from waste	1 300 000
Removal of organic waste from landfills	1 000 000
Total	**2 300 000**

8 Discussion

All relevant information as well as findings of the study have been presented in previous chapters. The discussion that follows aims to connect the research of the waste management and energy demand in Chile with the biogas substrate assessment through the results presented in the case studies. The comparison and potential of biogas and energy on municipal and regional level will also be addressed and the impact changes in the data could have on the presented values.

8.1 Challenges in the current system

The research of waste handling found several critical issues in the waste management system today. The economical aspect clearly is an issue, as waste handling today is considered cheap, but still causes debt among inhabitants and municipalities. More advanced technologies would be needed to perform a better recycling of waste on a higher level, if for example KDM Empresas would oversee the source separation and treatment, and it would therefore require taking a higher price from their customers. Since there is no legal enforcement of source separation of waste, the choice for municipalities and companies of paying more for better separation or continuing to pay for landfill disposal, is unfortunately leaning towards the latter.

A key could be that 75% of the cost paid for waste management is directly related to collection and transport. Since 58% of municipal waste consists of organic matter, sorting out more than half of the waste before sending the waste away, and instead treat it locally, could be an economically favourable option. The lack of funding causes an overall issue starting up new local projects, without knowing when they will start generating income. A good option would probably be an investment by an external actor, where the need of immediate economical profit might not be as important.

The classification of recyclable material in Chile in general leaves out organic materials. It might be since it is a more complex system with food for example being imported and exported compared to the materials from producers covered in the REP law. It may also be that organic material makes up a great part of the total waste in Chile today, and by enforcing laws regulating it would also generate thorough planning.

The governmental initiatives that recently have emerged, indicate that the issue is at least addressed by the country’s leaders. The Circular Economy Roadmap arises the question of interconnecting different parts of the society, to break the linear economy that is today and instead connect the ends with each other to form a circular material flow. Anaerobic digestion fits in perfectly in the circular economy since the organic waste can be used for both energy generation and to return the valuable nutrients to the lands through the digestate. The initiative is still newly launched and covers a broad range of materials and products, and risk is that organic matter will not be prioritized to a start.

The other initiative, addressing organic waste directly, is the National Strategy on Organic Residues. The strategy however holds very few concrete actions that can be taken by authorities in different social levels, and instead puts the responsibility on the inhabitants, to recycle their organic waste in domestic composts. In this way, they diminish the costs of implementation on municipal level, and will not get asked for economical means by municipalities. Since municipalities already struggle with payments for waste handling, it may be favourable for them with less organic waste in the municipal waste, but from a practical point of view, it may cause issues. Composts need to be handled correctly to not cause increased methane emissions, stench, or attraction of unwanted animals. The risk is that this initiative will lead to more damage than gain on a local level. Also, by composting the organic waste, the high energetic value of the material is not taken advantage of. A change of focus in the strategy towards implementation of anaerobic digestion on municipal or regional level would in the long run give a better outcome on all societal levels, as well as include organic waste to a greater extent in the Circular Economy Roadmap.

8.2 Outcome of the case studies

El Monte, as the only municipal presented in the study, showed an energy potential from pure sources, or the so called "lowest hanging fruit" from biogas (42 GWh) would cover the domestic energy need from gas or electricity from all houses in the municipality per year. As the results were presented to representatives of the municipality, the interest of taking advantage of the potential was high. Hopefully within some years, the case has been studied enough for them to take the step towards a municipal implementation. When adding organic matter today found in mixed municipal waste, another 9 GWh could theoretically be generated in El Monte, which would further increase their chances.

An important part of the biogas potential in El Monte comes from the waste produced by the slaughterhouse Ariztía El Paico, which contributes to over half of the total potential of the municipality. The numbers regarding this specific source were taken from a waste declaration, not specifying the type of waste, more than it being slaughterhouse residues. It might be that the biogas potential and methane content of the gas are much lower or higher, depending on the real data. It is also important to remember that Ariztía today sells most of their organic waste as substrate to animal food production. They did however express interest in biogas production during the interview, as long as it would be economically favourable in comparison to the profit that they gain from selling it today, or if it could lower their cost of sludge treatment. Chances are therefore that the organic waste from Ariztía El Paico is not available for biogas production, which would decrease the potential in El Monte drastically.

If the slaughterhouse waste from Ariztía would not be available, another problem in the mixture of El Monte's substrates would arise. The largest contributor would instead be chicken manure from the egg and chicken producer Avícola El Monte, and as mentioned in the description of biogas production system, chicken manure has a high content of nitrogen. Abundance of nitrogen is important to produce methane, but a too high ratio compared to carbon could cause a high formation rate of ammonia, which would lower the pH and thereby change the process conditions and end up inhibiting the biogas production. If the substrate mix contains high levels of chicken manure, an investigation of the effect on the biogas production would therefore be necessary.

The sources that could be considered the lowest hanging fruit in Providencia could through biogas production generate only 1 GWh per year. Due the high population, the domestic energy need from gas in the municipality is relatively high – 63 GWh per year. This means that by converting the biogas from the found sources to biomethane, would only cover about 2% of the domestic gas need in Providencia. However, if domestic food waste today found in mixed waste is incorporated in the model, 52 GWh could be generated, covering 81% of the domestic gas need in the municipality.

The biogas potential from the “lowest hanging fruit” in Providencia might also be misleading since the collection of data was very limited and obtained only through general data from SINADER and former studies handed out by representatives of the Department of Environment in the municipality. Moreover, the found data regarding restaurants was close to non-existing and given that there are many restaurants in the area, a high extra potential might be found, but left out in this study.

The fictive average municipality takes more substrate into consideration than the studied existing municipalities. Seen in the comparison in subchapter 7.4, the fictive municipality accounts for both much food waste from a high population, as the case of Providencia, as well as waste generation from rural industries such as egg and chicken producers, as found in El Monte. Wastewater treatment is also a large contribution to the biogas potential in the fictive municipality, that did not appear as an important waste stream in the other municipalities. The reason can be that wastewater treatment is not performed on municipal level in Chile, but instead by nationally operating companies such as Aguas Andinas that treat wastewater from several municipalities at one large facility. Since Aguas Andinas already produces (or at least did in 2009) biogas from their wastewater treatment, the contribution from this source in the fictive municipality might not even add to a “new” energy potential from biogas.

The potential could be compared between the municipalities in several ways. By looking at the energy potential per capita, El Monte has the highest yearly amount with over 14 300 kWh biogas/inhabitant, and Providencia reaches numbers of 400 kWh/inhabitant. The number of the fictive municipality may be seen as an average biogas potential per inhabitant in the region and lands on 560 kWh/inhabitant. If the yearly energy potential instead is put in relation to the area, Providencia outnumbers both El Monte and the average municipality with 2 200 MWh biogas/km^2 compared to 440 MWh/km^2 and 290 MWh/km^2 respectively. Depending on to what relation the comparison between the municipalities is made, the potential can therefore both be considered higher or lower in either of the two studied municipalities. Interestingly, both of the real municipalities present a higher potential per area than the fictive municipality, which might because El Monte has the massive slaughterhouse Ariztía El Paico in the municipality, and that Providencia is very small to the size, compared to the regional average.

The biogas potential on a regional level found in the study should furthermore be far from representative on a national level. Given that almost half of the population lives in RM that represents 4% of the area of Chile, the biogas potential per area in the region should be much higher than the national average. The biogas potential per capita in the region however is probably lower, due to the dense population in the capital, and the space for larger agricultural industries outside the region.

The biogas found in RM could potentially be used for electricity production or upgraded to biomethane to be used in national gas grids or as vehicle gas, as explained in subchapter 7.5. In absolute numbers, the energy potential could cover the energetic need of electricity or domestic gas use, but both these option holds many uncertainties. The electricity price is currently dropping due to cheaper generation from wind and solar, and the gas market remains owned by few but large companies, which means limited access for new gas producers.

Some examples where biogas already is produced through anaerobic digestion in Chile have been mentioned in the report. These examples are: through landfill gas extraction by KDM Empresas, treatment of wastewater by Aguas Andinas, the out-of-RM biogas production by Schwager Energy, and the pilot scale bioreactor in La Pintana. Among these, the gas at KDM Empresas is used for electricity production, at Aguas Andinas for biomethane production and at Schwager energy for heat (steam) generation. In La Pintana the use of the biogas remains unknown. The variation in the examples of uses for the biogas talks for its versatility, but also tells us that there is no direct path to where the gas fits into the Chilean structure perfectly. Both Aguas Andinas and Schwager Energy cooperates with gas distributors, which might be a necessity if the gas is to be used as biomethane or heat with the population as clients. KDM Empresas uses their gas to generate electricity, which was favourable at the time when they started 2011, but today is on the edge of closing, due to low electricity prices and the withdrawal of green energy certificates. Electricity production from the biogas is still the option that seems to be most popular amongst the municipalities. If the potential biogas production would take place on municipal level, this might an option.

8.3 Futuristic view of the biogas potential

A path that is less explored in Chile is to use the biogas to generate vehicle fuel. As explained early in the thesis in subchapter 2.2, RM faces problems with air-quality mainly from the transportation sector. In subchapter 4.5, the fact that the use of vehicle gas instead of conventional fuels lowers emissions from the transportation sector was presented. Since 80% representing about 30 000 tons/year NO_x emissions in the Metropolitan Region today comes from the transportation sector, it should be considered a focal point for when resolving the problem. The phenomena of thermal inversion will remain due to the topographic location of the region, and the only way to increase the air-quality, would be lowering the emissions. Biogas used for vehicle fuel should, according to the author, therefore be considered by Chilean government representatives, when planning the future of transportation.

What might be regarded an issue when generating vehicle gas from the biogas is distribution, especially if the aim would be to use it on a regional or national level. Today there are less than 10 000 gas vehicles in Chile, and the possibility to recharge your gas vehicles at any location is most likely very low. As the projection according to the Ministry of Energy also points towards electrification of the transportation sector, any change of the infrastructure for gas vehicles on a regional or national level is also unlikely to happen within a near future.

The biogas could however be used internally, if the same company that produces the vehicle gas also has a transport necessity. It could work with local buses and public transport, where the routes are set and recharging of the vehicles is planned. It might also be of interest for KDM Empresas generating their own biomethane to run their garbage trucks, where refilling the gas could be done at the same facility where it would be produced. Since they also have much of the gas cleaning equipment installed and technological knowledge gained, the step towards producing a purer product of biomethane should not be unrealistic. Today KDM Empresas has a total of 800 trucks, as mentioned in subchapter 5.2.2, and their fleet would require according to the energy need of a gas driven garbage truck in subchapter 4.5 about 100 GWh per year. This means that the biogas potential from the fictive average municipality

(86 GWh) would be almost enough to drive their entire national truck fleet on a yearly basis. By looking at the biogas potential from the "lowest hanging fruits" and thereby excluding food waste found in mixed municipal waste from the potential, three fictive average municipalities would be needed to cover the gas need for the trucks of KDM Empresas.

If the total found biogas potential of 4 500 GWh in the region would be taken advantage of and the gas upgraded to vehicle gas where 100 GWh would be used internally by KDM Empresas, the company could still sell the remaining biomethane to run almost 12 000 city buses, which corresponds to two thirds of the almost 18 000 buses that circulate RM today.

Another option could be that the municipalities themselves can treat their organic waste through anaerobic digestion, which is a possibility since there was generally a high interest from municipalities to take part of the results of this study. Both Departments of Environment in El Monte and Providencia have high hopes of finding better waste management solutions for their municipalities and the idolised example of La Pintana is often the reference point. La Pintana's capability of changing the waste management system is an inspiration, but in a way also forms an obstacle for well needed funds from the government to the waste management sector on municipal level. Since La Pintana managed to change their system without external funds, other municipalities are expected to follow without economical support by the government. It may be that it will happen with time, but after interviewing several municipalities, it stands clear that the reason for wanting a change in the system varies. Marchant at DIGA in La Pintana pointed out early in the interview that they do not care for short-lived economical profit, they want to implement a waste management system that can survive several generations. Although this was the optimal scenario for the other municipalities, the economical profit was still an important criterion.

Taking advantage of the regional biogas potential of 4 500 GWh could lower greenhouse gas emissions by about 2 million tons CO_2-eq per year, according to the result presented in subchapter 7.6. In this study, only the possible reductions of climate impact from replacing fossil diesel and removing organic waste from landfills were covered. Important to remember is that the same reduction could be made without biogas, for example by changing to electric vehicles that run on electricity from renewable energy instead of diesel trucks, or by improved management of emitted gases from landfills. As mentioned in chapter 5, landfill gas is to some extent already treated in RM by KDM Empresas, and the reduced climate impact from less organic waste in landfills might not make a great difference from this specific landfill.

With that said, there are also other parts of the life cycle of biogas production that could generate lower climate impact but are excluded in this study. For example, by replacing chemical fertilizers by digestate from anaerobic digestion. Implementing anaerobic digestion of the organic waste in Chile would therefore most likely contribute to the progress of lowering the national climate impact, no matter on which level in the Chilean society the implementation would take place. The national goal that was set 2007, aimed to achieve a national decrease of GHG emissions of 30% by 2030, which was mentioned in subchapter 5.2.4. The goal then required a decrease to emission levels of 63 million tons CO_2-eq per year. The statistics from 2018 instead showed increased emissions, with numbers of 110 tons CO_2-eq per year. The required decrease is therefore now 47 million tons CO_2-eq, or 43%, and by using the biogas potential found in this study, the national emissions therefore could potentially be lowered by 2%.

8.4 Recommendations by the author

Authorities in Chile should consider anaerobic digestion as a part of their waste management system since the advantages it would have on both their models for circular economy as well as their goal of lowering GHG emissions are many. More studies are needed to know on which societal level anaerobic digestion would be most suitable, as well to what purpose the biogas would serve the most. The aspects that need to be investigated to make a fair decision are for example substrate availability and optimal mixture compositions, as well as techno-economic analyses of both geographical coverage of substrate uptake, choice of reactor type and uses and distribution of the biogas.

9 Conclusion

The first research question presented in subchapter 1.1 asked how organic waste is handled in Chile today and what the possibilities are of integrating biogas in the Chilean energy demanding segments. The research of the two topics performed in this study shows that there are many challenges to overcome to make anaerobic digestion a part of the Chilean waste management and energy model. Several newly founded initiatives by the Chilean government, such as The Circular Economy Roadmap and The National Strategy for Organic Residues, as well as emerging companies as TriCiclos however indicates that the need for a change in the system is on its way, and that it might be the correct time to raise the topic.

The second question aimed to map out greater sources on municipal level in the Metropolitan Region that generate organic waste, investigate how much they generate on a yearly basis, as well as what type of organic matter they consist of. The study found several sources of various sizes and substrate types in two selected municipalities, as well as from general data. An average fictive municipality was constructed to mirror what waste flows could typically be found on municipal level in the region, which had an area of almost 300 km2 and 150 000 inhabitants. The average fictive municipality had both urban characteristics, such as high population, as well as rural characteristics, for example three vineyards and two slaughterhouses.

The third research question investigated the potential amount of biogas and energy that could be generated from organic waste, both on municipal level and in the region as a whole. The biogas potential from pure substrate flows was found to be higher in the semi-rural municipality of El Monte compared to the urban municipality of Providencia, due to the abundance of agricultural industries in the countryside compared to the centre of the city. The importance of organic waste in mixed flows as substrate in the biogas potential also varied in the studied municipalities. When including food waste found in mixed municipal waste, the potential in Providencia reached an absolute value close to the potential found in El Monte. The fictive typical municipality showed a biogas potential of 86 GWh per year and the region a biogas potential of 4 500 GWh per year.

The last and fourth question that was raised asked to what extent converting organic waste into biogas in the Metropolitan Region could improve waste handling and contribute to lower the region's greenhouse gas emissions. The study found that be implementing anaerobic digestion, the energy content in organic waste could be recovered to an extent that is not included in national guidelines today. By sorting out waste at the source, domestic food waste could also be used for energy, instead of becoming landfill material. If the regional biogas potential of 4 500 GWh would be recovered, Chile could reduce their greenhouse gas emissions by about 2 million tons CO_2-eq per year, representing 2% of Chile's total annual greenhouse gas emissions.

There is still a long road ahead for Chile to reach the circular economy they aim for. Hopefully, biogas generated through anaerobic digestion of organic waste will play an important role in their future roadmaps and strategies, to take advantage of the biogas potential found in this study.

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11 Apendices

Appendix 1. Interviews

List of actors where contact was established during the study.

Table 29. List of actors where contact was established during the study.

Name	Type of actor	Activity/Position
KDM Empresas	Company	Landfill owner and waste handling company in RM
Schwager Energy	Company	Technical consulting company with active bio digestors in Chile
TriCiclos	Company	Delivering recycling solutions to other companies in Chile
Reciclos Orgánicos	Governmental programme	Collaboration with the Government of Canada on recycling organic material
Division of Renewable Energy	Ministry	Ministry of Energy
Division of Circular Economy	Ministry	Ministry of Environment
WWF Global Cities	NGO	Worldwide recognized environmental foundation.
RedBioLAC	NGO	Network of bio digestors in Latin America and the Caribbean
Fundación Basura	NGO	Foundation of zero waste in Chile
Ciudad Emergente	NGO	Organization for sustainable city solutions
Department of Waste Management	Municipality	El Monte
Department of Waste Management	Municipality	Quilicura
Department of Environment	Municipality	La Reina
Department of Environment	Municipality	Providencia
Department of Environment	Municipality	La Pintana
Semillero Avenida San Miguel	Producer	Seed farm
Viña Doña Javiera	Producer	Vineyard
Avícola El Monte	Producer	Egg and chicken farm
Ariztía El Paico	Producer	Meat and dairy producer

List of people interviewed during the study, their title and contribution to the thesis.

Table 30. List of people interviewed during the study, their title and contribution to the thesis.

Name(s)	Title	Contribution to study
Arturo Arias	Technical and Environmental Manager at KDM Empresas	Waste handling, data collection
Viviana Ávalos	Professional at the Ministry of Energy	Energy demand
Geraldo Canales	Coordinator of Reciclos Orgánicos	Waste handling
Josefa Gutiérrez	Division Manager at Schwager Energy	Waste handling
Eduardo Miranda and Carolina Mendez	Director of Waste Management at the municipality of El Monte	Data collection
Tania Bishara	Division of Circular Economy, Ministry of Environment	Waste handling
Pilar Ogalde	Director of Waste Management at the municipality of Quilicura	-
Paula Gajardo	Head of Environment at the municipality of La Reina	-
Paloma Valenzuela Hernándes, Cristian Bravo, Maria Ramirez	Environmental Department of Providencia	Data collection
Felipe Marchant Villaseca	Director of Environmental Management of La Pintana	-
Agustin Correa	Director of New Businesses at Triciclos	Waste handling
Mariela Pino	General Coordinator at RedBioLAC.	Waste handling
Macarena Guajardo	Executive Director at Fundacion Basura	-
Anders Hjort	Project leader at IVL Svenska Miljöinstitutet	Biogas production systems, Case studies
Manuel Rojo	Member of Colectivo VientoSur	-
Jennifer Lenhart	Global Lead at WWF One Planet Cities	-
Javier Vergara	Co-founder of Ciudad Emergente	-
Pedro Juan Sahli Illanes	Semillero Avenida San Miguel	Data collection
Jorge Armillo	Viña Doña Javiera	Data collection
Ricardo Correa	Avícola El Monte	Data collection
Mariano Ruiz	Ariztía El Paico	Data collection

Prepared questions for the interviews

Interview with Arturo Arias 2021-02-05

- What does your business structure look like? Do you sign deals with municipalities or directly with companies generating waste?
- Does your service include picking up the waste or is it transported to you by your signed partners?
- Do you have data on what type of waste and how much per category is delivered to you from each contractor?
- Do you separate the waste, if so, on what basis?
- What is your treatment method of organic waste?

Interview with Viviana Ávalos 2021-02-08

- What is the energy production in Chile? From what sources?
- What is the energy requirement in Chile? What is the division between gas/electricity? Are the requirements met from national production or is import needed?
- What is the national situation of waste handling? How much is collected and how much is recycled?
- Which rules and recommendations are there to follow regarding waste management? On which level in the society is the waste handling regulated (nationally/per region/per municipality/per producer)? What are the methods to make sure the rules and regulations are followed?
- Is there any specific regulation regarding organic waste?
- Is biogas used in Chile? If so, is it imported or nationally produced, and to what scale?
- What does the energy market and its hierarchy look like in Chile?
- If a new actor wanted to produce biogas, what would be the advantages/difficulties? Would it be possible to sell the gas as fuel or as electricity? Would it be possible to gather waste from local actors such as supermarkets, or is there any law prohibiting it?
- What national goals are there on renewable energy and carbon dioxide emissions in Chile? What are the active steps taken to reach the goals? How are the people/companies encouraged to act to reach the goals? What is the prognosis of reaching the goals?

Interview with Gerardo Canales 2021-02-19

- What is the program of *Reciclo Orgánicos* and what projects do you have at the moment?
- Which are the treatment methods of organic waste does the program supports?
- What steps do you take when you reach out to a new municipality, and what are usually the main reasons why/why not a municipality wants to implement local treatment of organic waste?
- What are the results of your projects?
- Do you produce biogas/biomethane in any of the projects and what are the possibilities to compete with electricity/heating/natural gas in Chile?

Interview with Josefa Gutiérrez 2021-03-02

- Do you calculate the potential of the biogas depending on the content of the substrate before the project is conducted?
- Do you have projects on biogas with mixed organic substrate (not only lactose leftovers)?
- What are the costs associated with the biogas production? Inversion cost and operational costs?
- What are the gains associated with the biogas production for those that buy the service from you?
- What is the minimum substrate input that is needed for the production to be economically viable?
- What is the payback period of implementing biogas production?
- Have you considered upgrading the biogas to biomethane? Why/why not?
- Is the production of biogas subsidised in any way by authorities?

Interview with Tania Bishara 2021-03-16

- What are the pros and cons about the current administrational division regarding responsibility of waste management in Chile?
- What is the financing that the municipalities obtain that is supposed to go to waste management? Is there a minimum value they obtain from the government?
- What are the laws that are applicable on organic waste management? What responsibility does the larger industries have of their waste management?
- What are the future goals for Chile regarding circular economy, waste management and energy consumption?
- How does biogas fit in in the future of Chile?

Interviews with municipalities

The questions were used in the following interviews

- 2020-03-03 Eduardo Miranda and Carolina Mendez in El Monte
- 2021-03-18 Pilar Ogalde in Quilicura
- 2021-03-19 Manuel Rojo and Paula Gajardo in La Reina
- 2021-03-23 Cristian Bravo Riquelme, Maria Teresa Ramirez and Paloma Valenzuela Hernández in Providencia
- 2021-03-26 Felipe Marchant Villaseca

- From which of the following types of activities/companies is the municipality responsible for collecting waste?
    - Open air markets of fresh fruits and vegetables
    - Supermarkets
    - Agricultural production
    - Slaughterhouses
    - Bakeries
    - Food courts (in schools/universities/hospitals/office complexes)
    - Restaurants and coffee shops
    - Other production of comestible products

- Pet food shops
  - Maintenance of parks and recreational areas
  - Event centres
  - Garden and flower shops
  - Water treatment plants
- Are there any exceptions in terms of responsibility for collecting the waste? Are larger companies responsible for their own waste, for example?
- Who collects the waste? Is it someone directly employed by the municipality or do you buy the favour from another company?
- What is the procedure of the collection? Are there drop-off points where the companies leave their garbage or is there a garbage truck circling the municipality?
- What is the final destination of the waste today? Is the waste sorted and transported to different places, or is it all mixed and transported to the same place?
- Does the municipality have data of the composition of the waste per pick-up point or per company?
- What are the expenses associated with waste management in the municipality?
- What are the future perspectives of waste management in the municipality?

Interviews with producers of organic waste

These questions were used in the following interviews:

- 2021-03-17 Pedro Juan Sahli Illanes at Semillero Avenida San Miguel
- 2021-03-17 Jorge Armijo at Viña Doña Javiera
- 2021-03-23 Ricardo Correa at Avícola El Monte

- What does the waste flow principally consist of?
- Is the organic waste mixed with other waste?
- How much organic residues do you generate per day, month or year? Does it vary with season?
- Do you use compost or bio digestion today?
- Do you sell/donate any residues for animal food production?
- Do you pay an external contractor for the service of waste collection? If so, how much is the cost for the service?
- Is the waste dried before it is handled?
- Do you use additional fertilizers? What type, how much and what are the costs?
- Do you have a large need for heat, electricity or gas in any process on site?

Appendix 2. Data

Waste composition and population in Santiago de Chile per municipality

Table 31. Waste composition in Santiago de Chile per municipality (Arias 2021).

Percentage composition of waste by municipality

Municipality	Organic material	Paper and paperboard	Plastic	Glass	Metals	Other waste
Santiago	57%	12%	10%	4%	1%	16%
Cerrillos	57%	12%	10%	4%	1%	16%
Cerro Navia	57%	12%	10%	4%	1%	16%
Conchalí	57%	12%	10%	4%	1%	16%
El Bosque	57%	12%	10%	4%	1%	16%
Estación Central	57%	12%	10%	4%	1%	16%
Huechuraba	57%	12%	10%	4%	1%	16%
Independencia	57%	12%	10%	4%	1%	16%
La Cisterna	57%	12%	10%	4%	1%	16%
La Florida	57%	12%	10%	4%	1%	16%
La Granja	57%	12%	10%	4%	1%	16%
La Pintana	57%	12%	10%	4%	1%	16%
La Reina	57%	12%	10%	4%	1%	16%
Las Condes	57%	12%	10%	4%	1%	16%
Lo Barnechea	57%	12%	10%	4%	1%	16%
Lo Espejo	57%	12%	10%	4%	1%	16%
Lo Prado	57%	12%	10%	4%	1%	16%
Macul	57%	12%	10%	4%	1%	16%
Maipú	57%	12%	10%	4%	1%	16%
Ñuñoa	57%	12%	10%	4%	1%	16%
Pedro Aguirre Cerda	57%	12%	10%	4%	1%	16%
Peñalolén	57%	12%	10%	4%	1%	16%
Providencia	57%	12%	10%	4%	1%	16%
Pudahuel	57%	12%	10%	4%	1%	16%
Quilicura	57%	12%	10%	4%	1%	16%
Quinta Normal	57%	12%	10%	4%	1%	16%
Recoleta	57%	12%	10%	4%	1%	16%
Renca	57%	12%	10%	4%	1%	16%
San Joaquín	57%	12%	10%	4%	1%	16%
San Miguel	57%	12%	10%	4%	1%	16%
San Ramón	57%	12%	10%	4%	1%	16%
Vitacura	57%	12%	10%	4%	1%	16%
Puente Alto	57%	12%	10%	4%	1%	16%
Pirque	57%	12%	10%	4%	1%	16%
San José de Maipo	57%	12%	10%	4%	1%	16%
Colina	57%	12%	10%	4%	1%	16%
Lampa	57%	12%	10%	4%	1%	16%
TilTil	57%	12%	10%	4%	1%	16%
San Bernardo	51%	20%	26%	-	1%	2%
Buin	No information					
Calera de Tango	61%	8%	14%	-	1%	16%
Paine	57%	12%	10%	4%	1%	16%
Melipilla	57%	12%	10%	4%	1%	16%
Alhué	No information					
Curacaví	57%	12%	10%	4%	1%	16%
María Pinto	57%	12%	10%	4%	1%	16%
San Pedro	57%	12%	10%	4%	1%	16%
Talagante	57%	12%	10%	4%	1%	16%
El Monte	57%	12%	10%	4%	1%	16%
Isla de Maipo	57%	12%	10%	4%	1%	16%
Padre Hurtado	57%	12%	10%	4%	1%	16%
Peñaflor	57%	12%	10%	4%	1%	16%

Source: SUBDERE, 2018

Table 32. Projections of population and waste generation 2017-2013 per municipality in Santiago de Chile (Arias 2021).

Estimated population projection by municipality

Municipality	Population 2017	Population 2018	Population 2019	Population 2020	Population 2021	Population 2022	Population 2023
Alhué	6 835	7 022	7 214	7 405	7 536	7 649	7 756
Buin	101 743	104 338	106 986	109 641	111 934	114 028	116 032
Calera de Tango	26 704	27 309	27 913	28 525	29 019	29 470	29 880
Cerrillos	85 026	86 451	88 016	88 956	89 520	89 858	90 060
Cerro Navia	139 604	140 355	141 402	142 465	142 304	141 507	140 581
Colina	152 740	163 779	173 119	180 353	185 599	189 757	193 594
Conchalí	133 420	135 099	137 162	139 195	139 394	138 638	137 678
Curacaví	34 337	35 016	35 720	36 430	36 991	37 479	37 932
El Bosque	170 801	171 032	171 487	172 000	171 789	171 201	170 536
El Monte	37 901	38 593	39 296	40 014	40 620	41 179	41 711
Estación Central	148 730	166 174	186 426	206 792	214 470	217 664	219 897
Huechuraba	103 962	106 706	109 630	112 528	114 453	115 858	117 121
Independencia	105 437	117 277	129 691	142 065	147 655	150 074	151 890
Isla de Maipo	37 965	38 690	39 433	40 171	40 803	41 354	41 876
La Cisterna	95 652	97 125	98 790	100 434	101 126	101 313	101 377
La Florida	386 307	390 218	396 781	402 433	405 185	406 229	406 796
La Granja	122 518	122 392	122 454	122 557	122 028	121 170	120 249
La Pintana	187 970	188 255	188 748	189 335	189 454	189 321	189 151
La Reina	96 811	97 810	99 033	100 252	100 459	100 131	99 686
Lampa	107 662	115 058	121 528	126 898	131 436	135 461	139 266
Las Condes	307 708	315 183	323 309	330 759	335 296	338 541	341 183
Lo Barnechea	109 778	114 322	119 240	124 076	126 816	128 439	129 790
Lo Espejo	103 454	103 454	103 643	103 865	103 381	102 530	101 615
Lo Prado	100 771	101 803	103 111	104 403	104 405	103 732	102 923
Macul	123 420	126 804	130 467	134 635	136 278	137 079	137 735
Maipú	549 261	556 715	566 664	578 605	584 053	585 684	586 337
María Pinto	14 254	14 474	14 708	14 926	15 132	15 323	15 503
Melipilla	133 232	135 945	138 793	141 612	143 779	145 583	147 275
Ñuñoa	222 055	230 808	240 753	250 192	255 823	259 712	263 319
Padre Hurtado	67 299	69 538	71 852	74 188	76 219	78 091	79 925
Paine	76 659	78 650	80 711	82 766	84 379	85 759	87 059
Pedro Aguirre Cerda	106 257	106 605	107 205	107 803	107 409	106 496	105 483
Peñaflor	95 420	97 255	99 142	101 058	102 667	104 106	105 498
Peñalolén	253 606	257 714	262 268	266 798	269 296	270 707	271 854
Pirque	28 010	28 799	29 616	30 433	31 134	31 787	32 412
Providencia	147 826	151 042	154 446	157 749	160 043	161 568	162 837
Pudahuel	240 958	244 526	248 347	253 139	256 607	258 535	260 129
Puente Alto	604 744	615 557	629 743	645 909	655 033	660 361	664 370
Quilicura	222 048	232 342	243 112	254 694	261 993	266 818	271 385
Quinta Normal	118 503	123 648	130 284	136 368	138 904	140 055	140 964
Recoleta	165 663	173 464	182 088	190 075	193 605	195 185	196 073
Renca	154 637	156 567	158 717	160 847	161 959	162 517	162 854
San Bernardo	318 078	323 415	329 121	334 836	339 043	342 411	345 583
San Joaquín	99 371	100 566	102 027	103 485	103 871	103 704	103 420
San José de Maipo	17 540	17 897	18 275	18 644	18 917	19 131	19 330
San Miguel	114 641	120 174	126 088	133 059	136 835	139 729	142 549
San Pedro	11 229	11 468	11 706	11 953	12 132	12 274	12 412
San Ramón	86 770	86 575	86 521	86 510	86 017	85 274	84 495
Santiago	446 490	467 865	486 838	503 147	517 280	527 014	536 089
Talagante	77 899	79 158	80 489	81 838	82 900	83 814	84 670
Tiltil	20 268	20 661	21 066	21 477	21 783	22 033	22 262
Vitacura	88 716	91 198	94 020	96 774	97 695	97 651	97 388
Total amount	**7 508 690**	**7 702 891**	**7 915 199**	**8 125 072**	**8 242 459**	**8 310 984**	**8 367 790**

Source: INE, Base projection 2017. Estimates and projections 2002-2035, communes

Estimated waste projection by municipality

Municipality	MSW (ton) 2017	MSW (ton) 2018	MSW (ton) 2019	MSW (ton) 2020	MSW (ton) 2021	MSW (ton) 2022	MSW (ton) 2023
Alhué	1 418	1 457	1 497	1 536	1 563	1 587	1 609
Buin	48 607	49 847	51 112	52 380	53 476	54 476	55 433
Calera de Tango	11 662	11 926	12 190	12 457	12 673	12 870	13 049
Cerrillos	42 269	42 977	43 755	44 222	44 503	44 671	44 771
Cerro Navia	50 676	50 949	51 329	51 715	51 656	51 367	51 031
Colina	66 255	71 043	75 095	78 233	80 508	82 312	83 976
Conchalí	48 141	48 747	49 491	50 225	50 297	50 024	49 677
Curacaví	9 000	9 178	9 362	9 549	9 696	9 824	9 942
El Bosque	81 644	81 754	81 972	82 217	82 116	81 835	81 517
El Monte	11 500	11 710	11 923	12 141	12 325	12 495	12 656
Estación Central	78 233	87 409	98 061	108 774	112 813	114 493	115 667
Huechuraba	53 820	55 241	56 754	58 255	59 251	59 978	60 632
Independencia	46 200	51 388	56 828	62 250	64 699	65 759	66 555
Isla de Maipo	12 465	12 703	12 947	13 189	13 397	13 578	13 749
La Cisterna	42 790	43 449	44 194	44 929	45 239	45 322	45 351
La Florida	97 421	98 407	100 062	101 488	102 182	102 445	102 588
La Granja	66 424	66 356	66 389	66 445	66 158	65 693	65 194
La Pintana	71 449	71 557	71 745	71 968	72 013	71 963	71 898
La Reina	42 952	43 395	43 938	44 479	44 571	44 425	44 228
Lampa	36 912	39 448	41 666	43 507	45 063	46 443	47 747
Las Condes	124 761	127 792	131 086	134 107	135 947	137 262	138 334
Lo Barnechea	45 000	46 863	48 879	50 861	51 984	52 649	53 203
Lo Espejo	56 852	56 852	56 956	57 078	56 812	56 344	55 841
Lo Prado	35 501	35 865	36 325	36 781	36 781	36 544	36 259
Macul	55 996	57 531	59 193	61 084	61 830	62 193	62 491
Maipú	179 337	181 771	185 019	188 918	190 697	191 229	191 443
María Pinto	4 500	4 569	4 643	4 712	4 777	4 837	4 894
Melipilla	63 164	64 450	65 800	67 137	68 164	69 019	69 822
Ñuñoa	81 220	84 422	88 059	91 512	93 571	94 994	96 313
Padre Hurtado	24 813	25 639	26 492	27 353	28 102	28 792	29 468
Paine	29 728	30 500	31 299	32 096	32 722	33 257	33 761
Pedro Aguirre Cerda	44 356	44 501	44 752	45 001	44 837	44 456	44 033
Peñaflor	26 400	26 908	27 430	27 960	28 405	28 803	29 188
Peñalolén	70 111	71 247	72 506	73 758	74 449	74 839	75 156
Pirque	11 769	12 101	12 444	12 787	13 082	13 356	13 619
Providencia	63 214	64 590	66 045	67 458	68 439	69 091	69 634
Pudahuel	81 191	82 393	83 681	85 295	86 464	87 114	87 651
Puente Alto	220 966	224 917	230 100	236 007	239 341	241 288	242 753
Quilicura	101 583	106 292	111 219	116 518	119 857	122 064	124 154
Quinta Normal	60 620	63 252	66 647	69 759	71 056	71 645	72 110
Recoleta	81 556	85 396	89 642	93 574	95 312	96 090	96 527
Renca	52 239	52 891	53 617	54 337	54 712	54 901	55 015
San Bernardo	126 230	128 348	130 612	132 880	134 550	135 887	137 145
San Joaquín	57 522	58 214	59 059	59 903	60 127	60 030	59 866
San José de Maipo	8 164	8 330	8 506	8 678	8 805	8 905	8 997
San Miguel	46 398	48 637	51 031	53 852	55 380	56 552	57 693
San Pedro	1 800	1 838	1 876	1 916	1 945	1 968	1 990
San Ramón	49 938	49 826	49 795	49 788	49 505	49 077	48 629
Santiago	202 698	212 402	221 015	228 419	234 835	239 254	243 374
Talagante	27 600	28 046	28 518	28 996	29 372	29 696	29 999
Tiltil	6 192	6 312	6 436	6 561	6 655	6 731	6 801
Vitacura	46 756	48 064	49 551	51 003	51 488	51 465	51 326
Total amount	**3 008 013**	**3 089 699**	**3 178 545**	**3 266 048**	**3 314 200**	**3 341 891**	**3 364 759**

Source: Own elaboration with data from INE and SUBDERE

Data obtained from Semillero Avenida San Miguel and conversion to wet weight

Table 33. Data from Semillero Av. San Miguel and conversions made (Sahli Illanes 2021).

Substrate	Time period	Volume (m3/month)	Density (kg/m3)	Wet weight (tons/year)
Grass	May-August	1		
	September-January	2		
	February-April	0		
Total			400 (AVCalc LCC 2021)	5.6
Household waste (organic)	Each month	0.09	606 (EPA 2016)	0.7
Vegetable waste from rinsing the seeds	March-April	5		
	May-Februay	0		
Total			800[8] (Agriwise 2010)	8

[8] Density approximated as similar to haulm of root vegetables.

List of potential sources of organic waste in El Monte

Table 34. Potential sources of organic waste in El Monte. Made by author, data found through Google. The sources were evaluated and only a few were considered "big enough" to be relevant for the study.

Negocio
Ferias de verduras y frutas
Feria Mercadito Campesino: Miércoles
Feria Club Socios: Domingo
Feria Modelo: Sábado
Feria Villa O´Higgins: Viernes
Feria Villa América: Sábado
Feria Los Álamos: Viernes
Feria Los Álamos: Sábado
Supermercados
Tottus Express
Comercial Tierranegra
Supermercado Villa Eden
Minimarket Cascanueces
Super Bodega aCuenta
Almacen Donde la Verito
Producción agricultural
Viña Doña Javiera
Viña Monte María
Carnicerías
Cecinas Artesanales De León
Panaderías y pastellerías
Cocteleria Fragola
Donde Mallarauco
Amasandería Monte Verde
Los Hornitos de El Monte
Panadería Soantu
Casinos (escuelas/universidades/oficinas/hospitales)
Colegio Divina Providencia
Colegio de Santa Maria
Escuela Básica República del Ecuador
Escuela Emelina Urrutia
Restaurantes y cafeterías
Xiao Jinghong y Otro (Sushi)
Restaurant La Ramada
Cafe Karku
Restaurant Las Vegas
Pizza Colombiana
El Marino
Café Rohodis
Los Tapia
Delicias Montinas

Casa Roots Pizzeria
Cataros
Supremo Sabor
Cake and Rolls
Chancho Negro
El Paso Comida Rapida
Trece Trece
Don Del Lalo
Bon Appetit!
Tempura Coffee
Merkari Sushi y Pizza
Otra producción de productos comestibles
Avícola El Monte
Huevos San Miguel
Tiendas de alimiento para mascotas
Happy Pets
El Labrador
Mantenamiento de parques, cementarios y areas recreationales
Plaza Independencia
La patera
Cementerio Municipal El Monte
Plaza de Los Porotos
Parque Comunal Mapocho Norte
La Patera Bosque
La Turbina
Club de fútbol Santa Adela
Jardin Las Brujitas
Centros de eventos
Casona El Monte
Yamil El Monte
La Aurora Centro de Eventos
Iturrieta Eventos
Huertas De Chinigue
Florerías
Florería Margarita
Plantas de tratamiento de agua
Agua Purificada Vai Veri Limitada

Data of three high-density communities in Providencia.

Table 35. Data from three high density communities in Providencia (Valenzuela Hernándes et al 2021).

	POTENCIAL DE GENERACIÓN DE RESIDUOS ORGÁNICOS DE ORIGEN DOMICILIARIO EN LAS 3 COMUNIDADES OBJETIVO										
	EDIFICIOS	DEPTOS	HABITANTES	TON RSD (TON/MES)	ORGÁNICO (residuos de alimentos y otros RESORG)	ORGÁNICO (residuos de jardín)	INORGÁNICO NO reciclable (Ton/mes)	INORGÁNICO RECICLABLE (Ton/mes)	A RELLENO SANITARIO	resumen comunidades	
				0,039	50%	7%	10,85%	17,15%	15%	Kgs/día de res. orgánicos por comunidad	Total Kgs/mes de Res. Orgánicos
Comunidad Sector 2 Unidad Vecinal Providencia	14	292	584	23	11	2	2	4	3	367	11.000
Comunidad Sector 5 Unidad Vecinal Providencia	1	330	660	26	13	2	3	4	4	433	13.000
Comunidad Parque Inés de Suárez	33	396	792	31	15	2	3	5	5	500	15.000
TOTALES	48	1.018	2.036	79	40	6	9	14	12	1.300	39.000

List of supermarkets and restaurants in the municipality of Providencia

Table 36. Supermarkets in Providencia. List made by author and by (Valenzuela Hernándes et al 2021).

Supermarket	Selected for study?
Supermercado Unimarc | Av. Manuel Montt 1097, Providencia	Yes
Supermercado Lider | Manuel Montt 80, Providencia	Yes
Supermercado Lider | Av.Pedro de Valdivia 1885, Providencia	Yes
Supermercado Tottus | Av. Bilbao 451, Providencia	Yes
Supermercado Santa Isabel | Providencia 2178, Providencia	No
Supermercado Jumbo | Avda. Andrés Bello 2465, Providencia	Yes
Supermercado Santa Isabel | Av. Francisco Bilbao 2855, Providencia	No
Supermercado Lider | Av. Nva. Providencia 2249, Providencia	Yes
Supermercado Lider | Las Camelias 2875, Providencia	Yes
Supermercado Lider | Eliodoro Yañez 1185, Providencia	No
Supermercado Lider | Santa Isabel 170, Providencia	Yes
Supermercado Lider | Rancagua 0180, Providencia	Yes

Appendix 3. Calculations

Calculations and assumptions to obtain the biogas potential from wastewater treatment plants.

Tratamiento local Lo Chacon

The given data was that the plant treats 70 houses in the nearby area. According to the Chilean National Consumer Service (SERNAC 2003), the average housing in Chile consists of 5 people, which means that 350 people are connected to the plant.

According to Svenskt Vatten (Finnson and Lind 2020) each person contributes with 100 kWh per year in form of biogas. Using this data, the energy potential can easily be calculated.

$$Energy\ per\ year\ (GWh) = 10^{-6} * 100\ kWh/person\ * number\ of\ people$$

To reach the biogas potential in Nm^3 the calculation made in the "normal" case had to be performed backwards. The energy content of methane can be found in Chapter 2 Theory, and the methane content for sludge (65%) can be found in Table 38 in Appendix 4.

$$Biogas\ potential\ per\ year\ (Nm^3) = \frac{Energy\ per\ year\ (kWh)}{Energy\ content\ methane\ \left(\frac{kWh}{Nm^3}\right) * methane\ content\ (\%)} = \frac{100\ *\ number\ of\ people}{9.97 * 0.65}$$

The additional two wastewater treatment plants in El Monte

The data for the other two wastewater treatment plants in El Monte was given in wet weight of sludge and could therefore be used in the Model found in Appendix 4.

Calculation of average food waste from supermarkets in Sweden

The numbers below were found in a report from SMED (Jensen et al 2011) where the minimum numbers were their estimations and the maximum numbers taken from key numbers presented by Avfall Sverige 2006. The coloured lines in the table were calculated from the middle value between the minimum and the maximum.

Table 37. Food waste per supermarket depending on number of employees.

	Size	Number of employees *estimated (source)*	Kg food waste per employee and year	Total tons/year
Min	Large	20 (20+)	360	7.2
Max	Large	20 (20+)	1 200	24
Middle	Large			15.6
Min	Medium	15 (10-20)	623	9.4
Max	Medium	15 (10-20)	1 600	24
Middle	Medium			16.7

Calculations and assumptions made in case study 3

Population

$$Average\ population = \frac{Total\ population}{Number\ of\ municipalities} = \frac{8000000}{52} = 153846$$

Number of households

$$Number\ of\ households = \frac{Population}{Average\ number\ of\ people\ per\ household} = \frac{153846}{5} = 30769$$

Rurality

Deciding rurality for the fictive municipality could be done several ways. The majority of the inhabitants in RM lives in urban areas, but the urban municipalities are to the area small compared to rural municipalities. Thus, to be able to include some industries that are only found in rural areas, as well as waste from the population that live in urban areas, the fictive municipality was assumed to be semi-urban.

Area

$$Area = \frac{Total\ area}{Number\ of\ municipalities} = \frac{15403\ km^2}{52} = 296\ km^2$$

Area with trees maintained by the municipality

Due to the obtained area being large and the semi-urban characteristics of the fictive municipality, the urban area that would have trees maintained by the municipality was assumed to be 50%. From the study of foliar mass in Providencia, which is an urban municipality, 43 tons of biomass was accounted for, in a municipality that is 14 km^2.

$$Biomass\ per\ km^2\ in\ urban\ area = \frac{43\ tons}{14\ km^2} = 3.07\ tons/km^2$$

$$Biomass\ in\ fictive\ municipality = Area * Percentage\ urban\ area * biomass\ per\ km^2$$
$$= 296 * 0.5 * 3.07 = 454\ tons$$

Farmland area

Since we are assuming 50% urban fully urban area, it could be assumed that the other 50% is semi-rural or rural, perhaps similar to the characteristics of El Monte. The area of the fictive municipality was therefore compared to the area of El Monte to find a conversion factor.

$$Conversion\ factor = \frac{Area\ of\ rural\ characteristics}{Area\ of\ El\ Monte} = \frac{0.5 * 296}{118} = 1.25$$

In El Monte 920 ha of the area is fruit and vegetable farms. By using the conversion factor, we obtain the farmland area in the fictive municipality.

$$Farmland\ in\ fictive\ municipality\ = 9.2\ km^2 * 1.25 = 11.5\ km^2$$

Number of open-air markets

By using the statistics of inhabitants per open-air market on average being 17600 (see Chapter 6.3) we can calculate how many open-air markets should exist in the fictive municipality.

$$Number\ of\ markets = \frac{Number\ of\ inhabitants}{Number\ of\ inhabitants\ per\ market} = \frac{153846}{17600} = 8.74\ \approx 9$$

Number of supermarkets

Both Providencia and El Monte provided data from supermarkets that generated more than 100 tons of waste yearly. Since it from before was assumed that 50% live in an urban area and 50% in a rural or semi-rural, the information regarding inhabitants per supermarket from Providencia and El Monte could be used respectively.

$$Supermarkets\ in\ urban\ area = \frac{Population\ in\ urban\ area}{\frac{Population\ in\ Providencia}{Supermarkets\ in\ Providencia}} = \frac{0.5*153846}{\frac{150000}{9}} = 4.6\ \approx 5$$

$$Supermarkets\ in\ rural\ area = \frac{Population\ in\ rural\ area}{\frac{Population\ in\ El\ Monte}{Supermarkets\ in\ El\ Monte}} = \frac{0.5*153846}{\frac{36000}{2}} = 4.3\ \approx 4$$

In total this gives us 9 supermarkets in the fictive municipality.

Waste from supermarkets

An average of the eleven sources found in the study was used.

$$Organic\ waste\ from\ supermarkets\ in\ fictive\ municipality = 9 * \frac{406 + 21}{9 + 2} = 9 * 39 = 351\ tons/year$$

Number of vineyards and number of egg and chicken producers

To estimate the number of vineyards and egg and chicken producers in the fictive municipality, it was first assumed that only the 50% that is of rural characteristics will have this type of industry. Thereafter the conversion factor, CF (see calculation of Farmland area in this same sub-Appendix) was used on the number of respective industries in El Monte.

$$Number\ of\ vineyards\ in\ fictive\ municipality = CF * Number\ of\ vineyards\ in\ El\ Monte = 1.2 * 2 = 2.5\ \approx 3$$

$$Number\ of\ egg\ and\ chicken\ producers\ in\ fictive\ municipality = CF * Number\ of\ egg\ and\ chicken\ producers\ in\ El\ Monte = 1.2 * 2 = 2.5\ \approx 3$$

Waste from wastewater treatment

For the fictive municipality it was assumed that all wastewater from residential areas is treated in treatment plants within the municipality. The calculation to reach the biogas potential was made similar to the one for Tratamiento local Lo Chacon in El Monte, see Appendix 3.1.

Slaughterhouses

To estimate the number of slaughterhouses in the fictive area, the numbers already presented under the source of Ariztía El Paico in El Monte was used. 102 slaughterhouses generate 82 091 tons animal waste per year. Each slaughterhouse therefore generates 1 579 tons on average which means that in the each of the 52 municipalities, there should be 2 slaughterhouses on average.

Emission calculations

Emissions from fuel mixes were found in EG 2020:26 (Energimyndigheten 2020).

For vehicle gas:

- 18.9 g CO_2-eq/MJ for 90% biogas 2017
- 15.8 g CO_2-eq/MJ for 95% biogas 2019

Biogas emissions could from these equations be calculated to 12.7 CO_2-eq/MJ.

Diesel emissions were found as a reference value of 94.1 CO_2-eq/MJ in EG 2020:26 (Energimyndigheten 2020)

Difference per MJ of biogas and diesel therefore becomes 81.4 g CO_2-eq

1 kWh corresponds to 3.6 MJ.
The regional potential 4500 GWh = 16 200 TJ →
16 200 000 000 * 81.4 = 1 320 000 ton CO2-eq saved with biogas compared to diesel

Appendix 4. Model

Organic materials and their capacity in terms of biogas production

*Table 38. Substrates for biogas production, and corresponding data. Translated from Swedish and Spanish. *Data from fruit and vegetable residues.* (Avfall Sverige 2009, Chamy and Vivanco 2007, Hjort 2021, Svenskt Gastekniskt Center 2012).

Substrate	TS	Biogas yield		Methane content
	[%]	[Nm3/ton TS]	[Nm3/ton wet weight]	[%]
None	0	0	0	0
Bread	61	498	304	61
Citrus peels	21	490	103	58
Beets	25	600	150	53
Corn	30	573	172	56
Vegetable stalks	12	466	56	60
Fruit and vegetable residues	15	633	95	62
Wine making residues	15	700	105	62
Potatoes	25	744	186	53
Potato shaw	15	453	68	56
Potato flour	86	636	547	55
Hay	33	482	159	56
Straw	78	369	288	70
Plant and garden waste	60	250	150	60
Dairy products	20	735	147	67
Fish waste	42	1279	537	71
Feathers	45	238	107	74
Coffee grounds	28	439	123	63
Egg shells	82	35	29	72
Dog food (dry)	91	880	801	64
Slaughterhouse waste (gastrointestinal)	16	575	92	63
Slaughterhouse waste (blood)	10	830	83	63
Liquid manure from cattle	9	244	22	65
Liquid manure from pigs	8	325	26	65

Chicken manure (guano)	23	324	136	58
Sludge from sewage treatment plants	5	300	15	65
Mixed food waste (large-scale catering)	13	1146	146	ivl59
Mixed food waste (domestic)	33	618	204	63
Mixed food waste (restaurants)	27	689	186	63
Mixed food waste (supermarkets)	15	800	120	59

Screenshot of the model built in Microsoft Excel.

Pure substrate potential

Fill out:	Fill out:	Calculated:	Energy model:	
Code	Wet weight (ton)	Dry weight (ton)	Energy content (kWh/Nm3)	
s27	69517	22940,61	9,969072165	Source: SGC

Chosen model:					
Code	Substrate	TS %	[Nm3/ton TS]	[Nm3/ton wet weight]	Methane content %
s27	Mixed food waste (domestic)	33	618	204	63

Results:		Fill out:	Energy and effect	
Nm3 biogas	14177297	Time period (days)	GWh per time period	89,04073292
Nm3 methane	8931697	365	MW Effect	10,16446723

Mixed substrate potential

Up to 10 substrates

	Fill out:	Fill out:	Calculated:	Energy Model	
	Code	Wet weight (ton)	Dry weight (ton)	Energy content kWh/100% CH4	
1	s27	69517	22940,61	9,969072165	
2	s0	36	0	Results:	
3	s0	0,7	0	Nm3 biogas	14177297
4	s0	36	0	Nm3 methane	8931697
5	s0	5,6	0	Time period (days) Fill out:	365
6	s0	1000	0	Energy generation from given time period	
7	s0	1000	0	GWh per time period	89,04073292
8	s0	1000	0	MW Effect	10,16446723
9	s0	1000	0		
10	s0	1000	0		
	Total	74595,3	22940,61		

Chosen model:					
Code	Substrate	TS %	[Nm3/ton TS]	[Nm3/ton wet weight]	Methane content %
s27	Mixed food waste (domestic)	33	618	204	63
s0	None	0	0	0	0
s0	None	0	0	0	0
s0	None	0	0	0	0
s0	None	0	0	0	0
s0	None	0	0	0	0
s0	None	0	0	0	0
s0	None	0	0	0	0
s0	None	0	0	0	0
s0	None	0	0	0	0

Figure 46. Screenshot of the model built in Microsoft Excel (Source: Author)