Master's thesis

Evaluation of new alternatives to improve landfill waste diversion in Reykjavík, Iceland

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ABSTRACT

Waste management company SORPA treats most of the waste generated in Greater Reykjavík Area of Iceland. Some of the produced waste is recycled either in domestic locations or taken abroad for further treatment but every day a remarkable amount of solid waste ends up being landfilled to Álfsnes landfill near the capital. Landfilling solid waste should always be the last and ultimate option in waste treatment since it deposits the waste into the soil forever. The waste generation of modern consumer-society has been traditionally in close relationship with increasing living standards but the waste amount cannot keep increasing indefinitely because the space for final deposit is limited. Founding a new landfill site would be highly unfavorable and against the prevalent standards so something else needs to be done.

By examining the current waste management system and waste profile of SORPA, it was possible to evaluate and find new suggestions to improve solid waste diversion from Álfsnes landfill. Possibilities for solid waste diversion in the capital of Iceland were evaluated by studying the current situation of the waste management in Greater Reykjavík area in detail, followed by an analysis with ARVI analysis tool developed in Finland. Three alternatives were examined in ARVI tool; cost-effective, environmentally friendly and balanced, and the analysis was concluded with a more detailed inspection of each individual alternative to produce realistic and applicable improvements for the current setup to divert waste from the landfill. Emphasis in waste diversion was in municipal solid waste, proper sorting and recycling.

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TIIVISTELMÄ

Jätteenkäsittely-yritys SORPA käsittelee suurimman osan Islannin pääkaupunkiseudulla syntyvästä jätteestä. Osa jätteestä kierrätetään ja osa menee ulkomaille jatkokäsittelyyn, mutta joka päivä suuri määrä kiinteää yhdyskuntajätettä viedään läjitettäväksi Álfsnesin kaatopaikalle pääkaupungin läheisyyteen. Jätteen kaatopaikalle sijoittamisen tulisi olla aina viimeinen ja äärimmäinen vaihtoehto jätteenkäsittelyssä, koska tällöin jäte jää pysyvästi saastuttamaan maaperää. Nykyisessä kulutusyhteiskunnassa syntyvän jätteen määrä on ollut perinteisesti suorassa vuorovaikutussuhteessa elintasoon nähden mutta jätevirta ei voi kasvaa ikuisesti koska jätteen loppusijoitustila on rajallinen. Uuden kaatopaikan perustaminen on hyvin epäsuotuisaa ja vallitsevia standardeja vastaan, joten jotakin muuta on tehtävä.

Tutkimalla SORPAn nykyistä jätteenkäsittelyjärjestelmää ja jäteprofiilia oli mahdollista arvioida ja löytää uusia ehdotuksia Álfsnesin kaatopaikan jätevirran ohjaamiseksi muualle. Jätevirran ohjaamisen mahdollisuuksia Islannin pääkaupungissa kartoitettiin tutkimalla yksityiskohtaisesti SORPAn tämänhetkistä järjestelmää, jota seurasi Suomessa kehitetyn ARVI-työkalun analyysi. ARVI-työkalussa arvioitiin kolmea eri vaihtoehtoa; kustannustehokasta, ympäristöystävällistä ja tasapainotettua, ja analyysi päätettiin jokaiselle vaihtoehdolle yksityiskohtaisesti tehtyyn tarkasteluun mahdollisimman todenmukaisten ja käyttökelpoisten parannusten mahdollistamiseksi nykyiselle systeemille. Pääpaino jätteen muualle ohjaamisessa oli yhdyskuntajätteessä, kunnollisessa jätteen erottelussa ja kierrätyksessä.

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NOMENCLATURE

Álfsnes: The studied landfill

EEA: European Economic Area

GRA: Greater Reykjavík Area, originates from Höfuðborgarsvæðið (The Capital Region)

Gufunes: The location of Baling and sorting plant of SORPA

HC: Home composting

IRF: Úrvunnslusjóður – Icelandic Recycling Fund

MSW: Municipal solid waste

NWMP: National waste management plan

P&P : Pulp and paper

RDF: Refuse-derived fuel

SORPA: The name of the assigning company, the word itself conducted from an Icelandic word for waste, "*sorp*"

SRF: Solid recovery fuel

UAA: Umhverfis- og auðlindaráðuneytið – The Ministry for the Environment and Natural resources of Iceland

UST: Umhverfisstofnun, Environmental Supervision Division, Environment and Food Agency of Iceland

1 INTRODUCTION

According to the Rio Declaration (UAA 2002), the main focus of sustainable development is placed on systematic solutions for waste management and on products that do not cause damage to the environment. This means simply that it is necessary to strive to gain control of the growing quantity of waste accompanied with today's consumer society and decouple the relationship between increasing waste generation and economic growth (Mazzanti & Zoboli 2008). Solid waste management functionality is by large extent based on the population size, corresponding area, location and climatic conditions of the country which in turn characterize the general waste composition (Sasikumar & Krishna 2009). Changes in these features can set various challenges to solid waste management and without a doubt conditions vary greatly around the world (Williams 2005).

A country in far north-west Europe, Iceland, has a distinctive waste management system. Iceland is a small nation with a land area of about 103,000 km^2 (Thórhallsdóttir 2007), equivalent to about one third of land area of Finland but having only 320,000 inhabitants. Population density in Iceland is only 3.1 people per kilometer but approximately two thirds of the total population is living in the so called Greater Reykjavík area (GRA), an area consisted of Reykjavík city and six other neighboring municipalities which form a continuous inhabited area (Fischer 2013).

Municipal solid waste management activities are on the rise in Iceland (UAA 2002). The waste management scene of the country is influenced by harsh climatic conditions with heavy rains and frequent strong winds, high costs in waste transportation and disposal and inability of domestically treating certain waste fractions like plastic packaging and cardboard (SORPA 2013a). Despite the challenging conditions, waste reduction activities like recycling and re-use are gaining more attention and their importance is increasing as environmental awareness is growing among the citizens of Iceland (SORPA 2013a). Iceland became a part of European Economic Area (EEA) in 1994 and therefore was obliged to implement EU legislation pertaining to the waste management of Iceland. The parliament of Iceland, Alþingi, has signed an agreement on decreasing the landfilling of organic waste to 35% of 1995's levels before year 2020 (UAA 2002). That is why this thesis is attempting to improve especially the current organic waste management of GRA.

Assessment for an improved waste management plan in GRA is necessary because landfilling does not completely eliminate solid waste. Landfilling stores waste into the ground but it still poses a potential threat in future as the waste mass remains dormant (White et al. 1995). With population growth in hand, generated waste from various human activities keeps increasing while the preservation space for solid waste is limited (UAA 2002). Founding a new landfill is not an option in the near future (SORPA 2013a) so the most favorable option is to reduce the amount of solid waste entering the landfill in the first place.

The main goal of this Master's thesis is to find improved alternatives for waste management compared to the current solid waste disposal in Álfsnes landfill of SORPA by means of waste diversion. Comparison of the current setup and future alternatives is conducted using a potential assessment tool or tools to find new strategies to divert solid waste from landfilling and improve the current waste management system. A lot of information about modern solid waste management is available in scientific articles and books. However, as this is an individual study with its unique characteristics, further examination is required to maximize the most efficient use of analytical methods. Thesis includes a throughout review of SORPA's current solid waste management and waste profile to gain a better understanding how the waste management system functions in the capital region as it is at the time of this thesis being written. The review is followed by an analysis tool assessment to pinpoint important aspects for waste diversion and to evaluate what methods would be suitable for future waste management, concluding to the proposition of new future alternatives focusing on waste diversion from Álfsnes landfill.

Main objective of this thesis in the long run is to help SORPA reduce the environmental and economical costs of landfilling and improve the waste management system in GRA as a whole. Question to solve is to look for an answer to what are the economic and environmental impacts of diverting waste streams away from the landfill in Icelandic context. After the assessment has been completed in this thesis, SORPA should be able to use the results as guidance to improve its system as described above. Decisions made in this thesis are meant to offer a proactive solution on how the waste management could be improved, not how the system should be unquestionably changed. Main focus is set on waste diversion from the landfill and this thesis will have only a minor focus on where the diverted waste should be forwarded for treatment apart from some suggestions how a share of waste fractions could be utilized further. SORPA has a more profound understanding of waste export and treatment in Iceland in addition to the functions of its own facilities and processes (SORPA 2013a).

2 WASTE MANAGEMENT IN ICELAND

2.1 Solid waste management, landfilling and waste diversion

The amount of waste produced in the world has been growing considerably for many decades particularly in affluent countries as there has been a strong connection between national gross domestic product (GDP) and waste generation per capita (Giusti 2009). Waste management hierarchy based on the most environmentally sound criterion favors waste prevention, waste minimization, re-use, recycling, decomposing and composting. However, in many countries, a large proportion of waste cannot be currently re-used, recycled or composted and main disposal methods are landfilling and incineration of solid waste (Giusti 2009). Waste incineration is often an unfavorable option for waste disposal as it is prone to produce CO_2 and hazardous particle emissions (Dezhen & Christensen 2010) while landfilling of solid waste is a widely utilized but environmentally obscure disposal method around the globe. In Europe alone, 57 % of MSW was landfilled in 1999 (Giusti 2009) and according to the European Commission report from 2011, the share of landfilling in the EU-27 countries had dropped from 68% in 1995 to 38% by 2008. Even though there was a remarkable decrease in the amount of waste ending up to permanent disposal, in 2008 EU-27 was still landfilling approximately 100 million tonnes of MSW (Zorpas & Lasaridi 2013).

Waste management of municipal waste is considered a public service, providing citizens a system of disposing of their waste in an environmentally sound and economically feasible way (Beigl et al. 2008). It is commonly recognized fact today that a higher degree of recycling in waste management contributes to both economical and environmental benefits by making use of the materials which would be otherwise wasted, simultaneously removing waste from entering a landfill (Williams 2005). Recycling solid waste is becoming even more important as waste generation rates are increasing globally. Policy-makers must decide which recycling practices to implement from the host of options at their disposal to best divert waste from landfill (Mueller 2013).

Waste diversion or landfill diversion is the process of directing waste away from landfill. Diverting waste from a landfill is done through recycling, composting, burning, compacting or any other means to reduce the threat of solid waste to human health and the environment (Thompson et al. 2012). Motivation behind diverting waste in the first place usually lies in the waste quality or excessive quantity of exploitable waste fractions as waste with high value or high environmental risk is often desired to be removed from the waste stream towards permanent disposal (Sasikumar & Krishna 2009). Waste diversion was most likely referred for the first time with its current description by EPA in the waste management scene of United States when environmental issues first started to gain notable public attention in the late 1980's (Hickman 2003).

2.2 History of Icelandic solid waste management

The earliest official records of Icelandic waste management date back to 1970's (UST 2006), when open-pit burning and incineration of solid waste was a common practice throughout the nation. Waste incineration was widely practiced around the coastline of Iceland in various cities until 1990's but with the disadvantages of generating a lot of thick smoke, smell and particle emissions to the surrounding environment as well as far-reaching emissions assisted by strong winds, it was then almost completely given up when landfilling of solid waste took place as a more effective and controlled waste treatment. Alongside the open-pit burning was also some high-efficiency incinerator stations which were built to handle larger quantities of waste with lower environmental stress and minor energy recovery in a form of thermal energy (UST 2006).

Due to increased cooperation between municipalities in Iceland, waste management became more efficient in the end of 1990's when there was a total of six landfills, three incineration plants and less than 50 burning pits in operation. Icelandic waste management had also a large impact from the foundation of SORPA, a company that handles the majority (,63% by an estimation) of all the generated waste in Iceland today (SORPA 2013a). After joining the European Economic Area (EEA), Iceland became obliged to implement European Union legislation to its waste management and in the beginning of 2000's open-pit burning was almost given up completely while 29 landfills and seven incineration facilities were in operation. Since 1990's, municipalities in Iceland started to gather their waste and clarify their current waste treatment chain (UST 2006).

Waste generation in Iceland has grown steadily over the past monitored 40 years along the population growth (UST 2006). With higher demand and increasing waste amount, waste management has become a business activity in Iceland. The number of waste treatment facilities is now lower and they have become bigger than before in order to make waste collection easier to access for public and more efficient for waste treatment (SORPA 2013a). The ministry for the Environment in Iceland was established in 1990 and soon after the Rio conference held by United Nations, the environmental awareness in Iceland got its first spike. An act on environmental impact assessment of Iceland was first made in 1993 and next edition came out in 2000 (UAA 2002). The first national plan of waste management was published in 2004 by the Environmental Agency and it has been updated frequently since its publication. In close relation to the national plan, municipalities in Iceland have been permitted to create their own waste management plans to meet the requirements set in the national plan (UST 2006). In accordance to meeting the standards of EU regulations, the Icelandic Recycling Fund (Úrvunnslusjóður – IRF) was set up in 2002 to manifest and improve the recycling in Iceland further by collecting recycling fees on hazardous waste, end-of-life vehicles and other waste fractions that are likely to involve additional costs in their handling (UST 2006).

In the near future, the amount of waste generated per capita in relation to GDP is estimated to steadily increase in a global scale (Giusti 2009) as the economical and environmental costs associated to landfilling are increasing at the same time (Mazzanti et al. 2009). The population of Iceland is estimated to reach 500.000 individuals by 2050 and based on the current population of Iceland; the majority of new citizens are likely to settle to Greater Reykjavík area (GRA) which increases the demand on more efficient waste management in future (UAA 2002). Icelandic waste management is on its way to become a recycling oriented society rather than a consumer society but further work is required until that goal is achieved (Fischer 2013).

Next milestone in Icelandic waste management is to meet the requirements set by the European Union before 2020 and continue to develop the national waste management from consumer oriented to recycling oriented system (UAA 2002). There has been very little discussion concerning for example the reduction of greenhouse gas emissions but the emphasis in biodegradable waste set by European Union is already a spot on solution to reduce the above-mentioned emissions (SORPA 2013a).

2.3 Challenges in Icelandic solid waste management

The solid waste management of Iceland differs in several ways from the mainland Europe. The land area in Iceland is rough and sparsely populated and the country does not have the full capacity of handling all waste it produces (Thórhallsdóttir 2007). Whereas Iceland has one of the highest percentages of recycled electronic appliances in Europe (UST 2006), many of the generated waste fractions need to be shipped abroad for further treatment (SORPA 2013a).

Climatic conditions of Iceland can make the waste management challenging. Occasional strong winds blowing throughout the country affect both the waste collection and landfilling of waste. Transportation and landfilling of solid waste is arranged to fit the changing weather (SORPA 2013a). Solid waste is compressed to bales and transported from Gufunes plant to Álfsnes landfill in special truck containers to prevent the unnecessary scattering of waste (SORPA 2013a). The wind along with rain and snowfall are also rather common in Iceland especially during the coldest months from November to March. Downpour can unnecessarily moisten the landfill mound and increase the water flow through the landfill turning water into leachate which is known to have a harmful influence to the surrounding environment (UST 2006).

During winter, average outdoor temperature is a bit above zero and during summer it usually stays slightly below +20^{o}C in GRA. Effective growing season lasts only about four months in Iceland, limiting the formation and landfilling of garden waste only to the warmest time of the year (Thórhallsdóttir 2007). When the average temperature is relatively low throughout the year, the chance for landfill or the organic waste landfilling pit to generate unwanted smell remains lower compared to any warmer countries (SORPA 2013a). Lower average temperature can also slow down the decomposition process of biodegradable waste and turn it into anaerobic process in some parts of the mound, resulting into bad odors (Themelis & Ulloa 2006).

Additionally, incineration of waste for energy production in Iceland is not an optimal waste treatment. Thermal energy is naturally abundant which makes the heat production from solid waste unnecessary as the current method is more cost-effective. The energy potential of solid waste could be manifested better by using some other treatment method (SORPA 2013a).

2.4 Icelandic law and EU legislation on solid waste management

Waste management legislation of European Union has been the basis of Icelandic national waste management plan for over a decade now. Iceland joined the European Economic Area (EEA) in 1994 and has since been obliged to implement the waste management regulations and laws of European Union. Before joining the EEA, Iceland had a set of laws regulating especially landfilling and recycling of hazardous and long-scale harmful materials, including law no. 56/1996 on hazardous waste fee and law no. 52/1989 on deposit system of non-refillable aluminum, steel, plastic and glass packaging both replaced now with law no. 162/2002 on Recycling Fees (UST 2006).

As law no. 55/2003 on Waste management stipulates, the Environment Agency of Iceland (Umhverfisstofnun, UST) is responsible for the implementation of the National Waste Management Plan (NWMP) which was released for the first time in April 2004 (UST 2006). Law no. 55/2003 is one of the most important laws regarding Icelandic waste management as it includes various regulations. Based on law no. 55/2003, three important regulations were issued; regulation no. 737/2003 on treatment of waste, no. 738/2003 on landfilling of waste and no. 739/2003 on incineration of waste to further implement the Landfill Directive (1999/31/EC). The Landfill Directive obliges the member states of EEA to reduce the amount landfilled biodegradable municipal waste to 35% of 1995 levels by the year 2020 (UST 2006). SORPA’s ideal goal is to decrease the amount of landfilled biodegradable waste to 6% in future before the date set by EEA (SORPA 2013a).

Law no. 55/2003 together with regulation no. 737/2003 stipulates the following EU target to Icelandic law which is most relevant for this study: to reduce the total weight of organic household waste or other organic waste such as biodegradable waste to be landfilled by 25 per cent by no later than 1 January 2009, by 50 per cent by no later than 30th of June 2013 and by 65 per cent by no later than 30th of June 2020 (UST 2006).

National Waste Management Plan (2002) states that the municipalities in Iceland are encouraged to make their own waste management plans and this goal has been already implemented throughout the country. In accordance with NWMP, Regulation no. 737/2003 on treatment of waste makes the local authorities responsible for collection, handling and treatment of municipal waste which is conducted by SORPA in the GRA (UST 2006). In addition, the above-mentioned Regulation no. 738/2003 provides for the ban on landfilling of scrap metals including end-of-life vehicles, liquid wastes and hazardous wastes as well as contagious waste and tires. The ban on landfilling of tires took effect on July 16th of 2006 but before that date the landfilling of shredded tires was allowed (UST 2006). SORPA has also used a fraction of shredded tires as a base material for some of its infrastructure in Álfsnes landfill (SORPA 2013a).

3 MATERIAL

3.1 SORPA bs.

SORPA bs. is a municipal intercommunity company based in the capital of Iceland, Reykjavík. It was established in 1991 and it is owned together by seven municipalities of the capital area: Reykjavík, Kópavogur, Hafnarfjörður, Garðabær, Álftanes, Mosfellbær and Seltjarnarnes and it is one of the oldest environmental companies in Iceland. SORPA is responsible for running the landfill in Álfsnes, Baling and sorting plant in Gufunes, smaller waste collection sites called drop-off points and processing all waste from all the municipalities which own it. SORPA is responsible for treating all waste generated in the capital region. However, SORPA is not responsible for waste collection which is independently run by third party companies in each municipality. In a case of mutual agreement (as mentioned in SORPA's Articles of Incorporation), SORPA is allowed to take the initiative and present propositions for coordination and economization of the waste management in GRA (SORPA 2013a).

SORPA has adopted ISO 14001(:2004), an international standard for environmental management systems, to three of its facilities: Baling and sorting plant at Gufunes, the landfill at Álfsnes and the offices respectively. The standard is based on the same foundations as the ISO 9001(:2008) quality management standard which SORPA has acquired the certification earlier in 2011 (SORPA 2013a).

SORPA is the biggest operator in Icelandic waste management scene and was employing over 90 people in 2013. In addition to being a major waste management operator in GRA, SORPA has its important input in education of younger generation of Icelanders in environmental awareness and sustainability. SORPA's main focuses in waste management are cost-effectiveness and the long-term interests of the community (SORPA 2013a). All real-life data used in this thesis are acquired directly from SORPA's headquarters in Gufunes, Reykjavík. The real-life data from years 2012 – 2013 are used in both theoretical and analytical part of the thesis. As a part of the work, I have been granted an access to SORPA's waste management data in order to achieve the best possible result in data analysis. I am counseled and supervised for this thesis in collaboration from University of Jyväskylä in Finland and SORPA bs. of Reykjavík in Iceland. I will write this thesis entirely in English and I will reside in Iceland for the time of my writing to gain a better understanding of the case I am working on.

3.2 Waste treatment at SORPA

According to SORPA's company guidelines (SORPA 2013a), the final disposal of solid waste should always be the last and ultimate outcome in the processing of solid waste. Hierarchical steps in usual waste management before landfilling are energy production, recycling, re-use and minimization of waste (SORPA 2013a). SORPA operates currently a total of 83 drop-off points along 6 recycling centers where citizens, businesses and industry of GRA are allowed to bring their solid waste or recyclables in exchange for handling fees based on the type, quality and quantity of waste (SORPA 2013a).

GRA has approximately 84.000 municipal households (SORPA 2013a) and third-party contractors are collecting their waste on a weekly basis. Municipal households have normally two different bins, a gray bin for MSW which is now referred as an energy bin and a blue bin for paper, cardboard and corrugated cardboard (Figure 1). Additionally, collection containers separately for both P&P and plastic packaging exist in various locations around GRA. Reykjavík city has also banned the disposal of paper and cardboard packaging to energy bin (general household waste bin) in order to recycle more P&P products (SORPA 2013a). While the blue bin thrives to get more P&P sorted, the energy bin waste is turned in for mechanical separation of metals by a magnet and it is estimated that up to 58% of metals in MSW have been successfully sorted (SORPA 2013a). Waste fractions like newspapers and magazines, cut-offs from corrugated cardboard, garden waste and tree branches are free to deliver but a recycling fee is charged on arrival from more complicated waste fractions like tires, plastic film and clean cardboard packaging (SORPA 2013a). SORPA also accepts a multitude of other waste fractions like shoes, refrigerators, electronic appliances, furniture and second hand items in recycling centers around GRA (SORPA 2013a). After the acquisition, solid waste is transported to Gufunes Baling & Sorting plant where a part of recyclable fractions is sorted from waste. The residual MSW is then baled to cubes and transported to Álfsnes for landfilling (Figure 1).

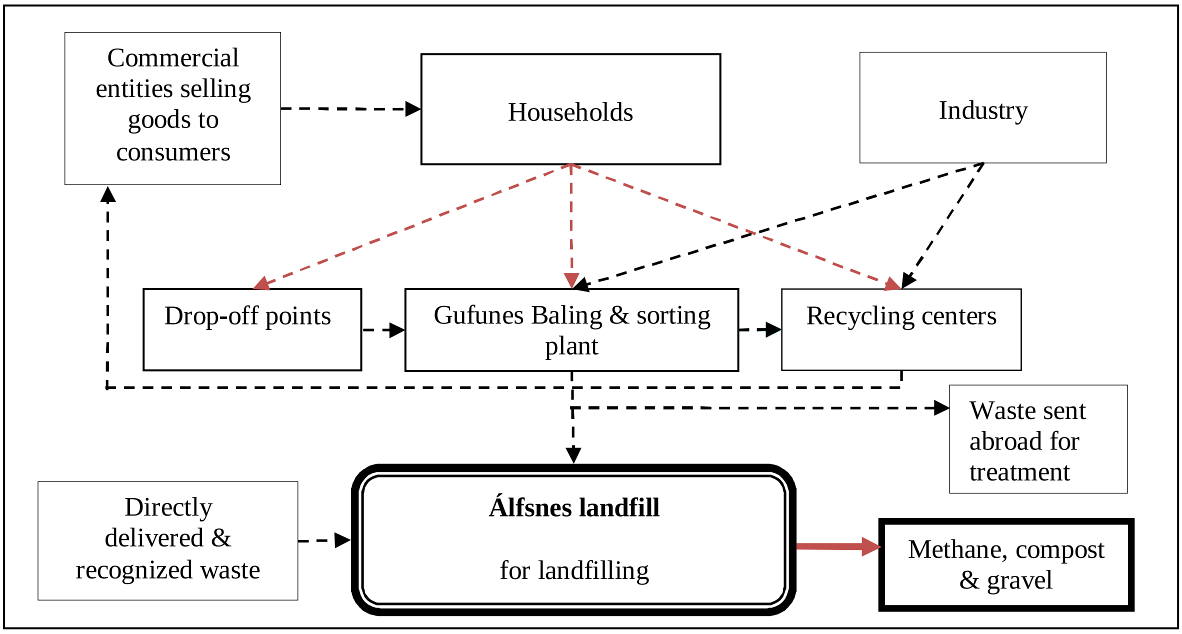


Figure 1. Simplified waste circulation picture of GRA. Thin lines resemble the waste input to the landfill, thick lines stand for outputs.

3.3 Gufunes Baling & sorting plant

The Baling and sorting plant of SORPA in Gufunes was opened in April 1991 along with the new landfill in Àlfsnes and the first office of SORPA on the side (SORPA 2013a). Naturally, the precondition for reuse and recycling is correct sorting of waste and thus the solid waste designated for landfilling is first sorted in Gufunes before transporting waste to their respective destinations. Majority of the solid waste goes to Álfsnes landfill but there are also several waste fractions that cannot be landfilled or which have a better use as recyclables such as the pre-sorted proportion of P&P, plastic packaging and magnet-sorted metals (SORPA 2013a).

Several waste fractions brought to Gufunes are exported for further treatment since either SORPA or the whole country does not have the capacity or technology to treat waste domestically. Among those untreatable waste types are baled plastic, corrugated paper, cardboard and newspapers which are sent to Göteborg, Sweden for IL Recycling for handling, scrap metal to Fura in Sweden (except for Vaka Is. which is taking care of the collection and handling of used cars in GRA), some of the wood residue to Elkem ferro-silicon plant at Grundartangi in North-west Iceland, textiles like second-hand clothes to Red cross and glass to domestic recycling. Part of the environmentally hazardous waste is taken to Efnamóttakan Ltd. while the rest is sent abroad for further treatment (SORPA 2013a).

Over the years, SORPA has taken more waste fractions to sort from solid waste, both before and after the waste arrives to the Gufunes plant (SORPA 2013a). Gufunes plant handles commercial, industrial and municipal household waste which is either collected around GRA by third party contractors or brought to the plant by corresponding businesses. Industrial and commercial parties are entitled to bring their waste to either Gufunes plant or straight to Álfsnes landfill (SORPA 2013a). At the plant, all waste enters first a weighing bridge before being unloaded and baled at the plant. MSW, plastic and cardboard (Figure 2) are baled while only residual MSW is taken to Álfsnes. Solid waste is wrapped into bales with steel wire and then the bales are taken to Álfsnes landfill in closed truck trailers to prevent waste from spreading around in wind. Trailers holds usually 25 to 30 tonnes worth of waste bales and each bale is sized about 1.1 m^3 with an average density of 895 kg/m^3 (SORPA 2013a).

Figure 2. Baling machine in use at Gufunes Baling & sorting plant (SORPA 2013a).

The amount of organic content in collected municipal waste has remained high over the recent years at Gufunes plant but waste fractions like P&P and timber have recently shown a slight decrease in quantity (Table 1). On the contrary, the amount of arriving plastic, minerals, glass and kitchen waste has been increasing lately. Especially the recent increase of plastic content in municipal solid waste is remarkable since the waste fractions in rise are the ones that should be given special attention when planning waste diversion. As per capita consumption along the increased use of product packaging waste tends to increase over time (Giusti 2009), it is reasonable to expect a slight increase in solid waste amount in future unless the consumption habits of consumers will not change. The overall waste quantity over the course of last 5 years has remained mainly similar with only minor changes (Table 1). This is likely because of the improved waste treatment SORPA has carried out but it does not mean that the overall waste amount would not have risen in the meantime.

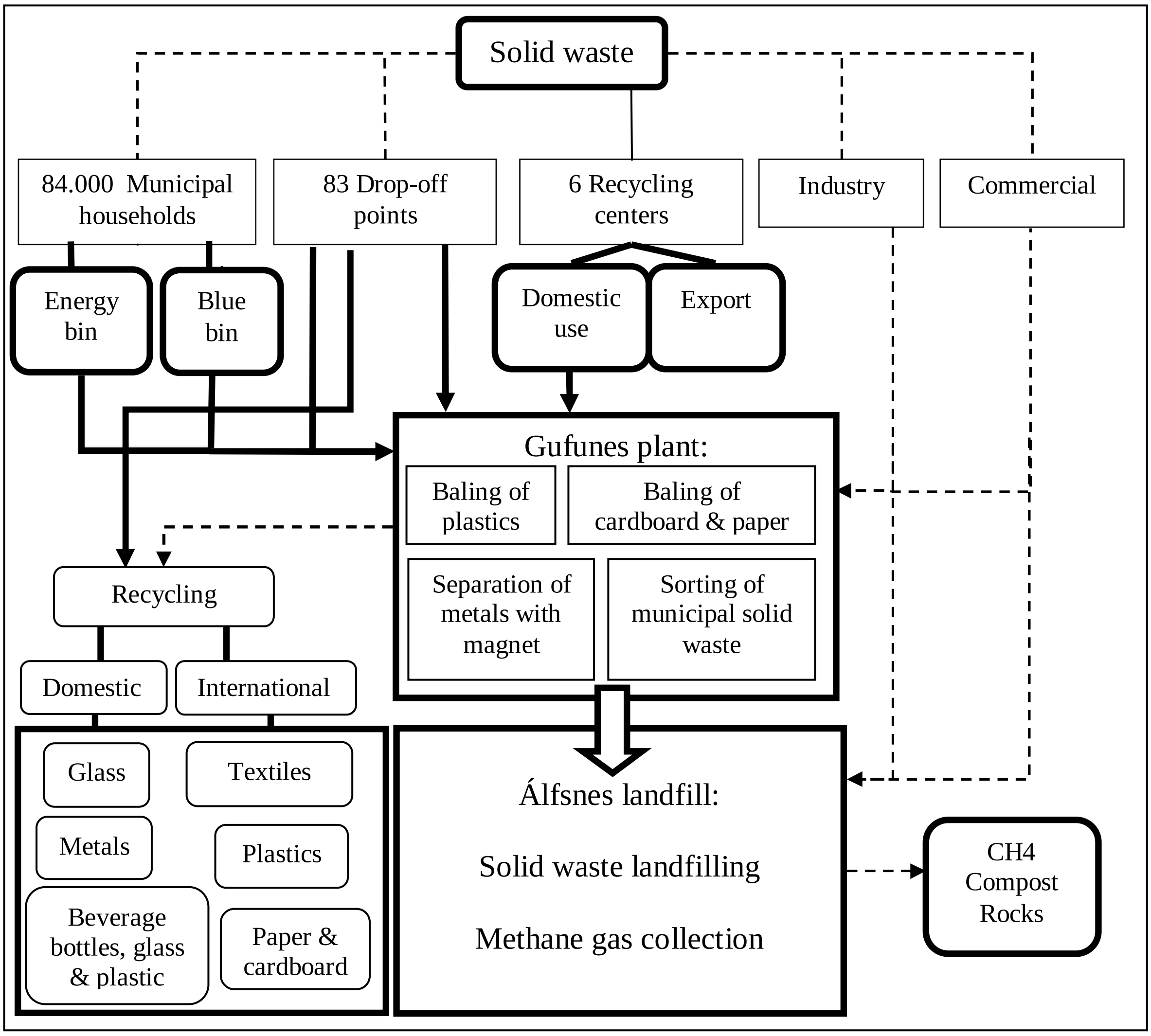
Table 1. MSW characteristics in relative percentages out of 100% collected waste from recent years in GRA (SORPA 2013d).

Waste category/Year	2007	2008	2009	2010	2011	2012
P&P	30.9%	27.6%	15.9%	23.8%	23.7%	20.9%
Plastic	14.5%	15.4%	17.0%	19.8%	16.2%	19.0%
Deposit items	1.7%	3.1%	2.1%	1.6%	1.3%	1.2%
Fabric	3.1%	4.0%	4.9%	2.3%	2.8%	2.5%
Candles	0.0%	0.0%	0.2%	0.1%	0.1%	0.2%
Metals	2.4%	2.7%	2.6%	2.2%	2.6%	3.2%
Minerals & glass	3.0%	3.4%	5.0%	3.6%	4.5%	5.0%
Timber	1.1%	1.0%	0.7%	0.6%	0.8%	0.6%
Kitchen waste	25.0%	21.9%	28.6%	23.1%	38.1%	37.7%
Garden waste	0.7%	0.7%	1.4%	1.1%	1.3%	1.0%
Hazardous/electr.	0.7%	0.6%	0.4%	0.8%	0.7%	1.9%
Diapers	5.5%	5.1%	8.3%	8.0%	8.0%	6.6%
Rubber/litter	11.3%	14.4%	13.1%	13.2%	0.0%	0.3%
Organic waste	66.3%	60.3%	59.7%	58.8%	74.6%	69.6%
Inorganic waste	33.7%	39.7%	40.3%	41.2%	25.4%	30.4%

3.4 Álfsnes landfill

Álfsnes landfill is currently the only landfill in GRA, located northeast from Reykjavík. Baling and sorting plant in Gufunes concentrates most of the waste brought to Álfsnes and both locations are run by SORPA. Álfsnes is a sanitary landfill and has approximately 44 hectares wide area (including the infrastructure) reserved for solid waste. Álfsnes was founded in 1991 and it receives every day approximately 300 tonnes of baled municipal solid waste and 50 to 100 tonnes of other waste throughout the year. It has a designated 50 meter depth limit for waste but because of the compressing and overfilling of solid waste, current depth levels vary around the landfill. Despite the vast land area, littering due to strong winds has not been reported to be a problem at Álfsnes (SORPA 2013a). The waste collection and treatment network of SORPA ending to Álfsnes consists of multiple separate entities (Figure 3).

Figure 3. Solid waste collection, transportation and disposal in SORPA's facilities in GRA (SORPA 2013a).



On the side of the landfill is operating Metan Is., a daughter project of Álfsnes which utilizes the landfill gas generated in the mound. Impure methane gas is first collected through the installed piping system in the mound and then purified in the gas collection facility (Figure 4). Methane gas is sold and used as vehicle fuel in GRA and a part of the gas is used for electricity production (SORPA 2013a). Some waste fractions brought to Álfsnes are used for recycling like yard waste, glass, horse manure, treated wood shavings and minerals. A gradient of waste fractions are also used for road surfacing and infrastructure instead of rocks, gravel and sand which would otherwise have to be delivered separately to the landfill (SORPA 2013a).

Landfill consists of the main disposal area reserved only for mixed solid waste brought in as bales and several other fields designated for other waste fractions (Figure 4). Field G is the current location where solid waste is buried while field A is currently just as a deposit area. Field A is covered with the methane collection piping system and collected gas is continuously pumped to the field D where it is purified and stored for later use (Figure 4). Field B is the current covered pit for organic waste, field C is the deposit area for garden waste after field J was filled up, field E is for glass and porcelain waste and field F is reserved for construction waste only (Figure 4). Remaining space in fields H, I, K, and L is just rocks, gravel or free space for contractors and future utilization (SORPA 2013a).

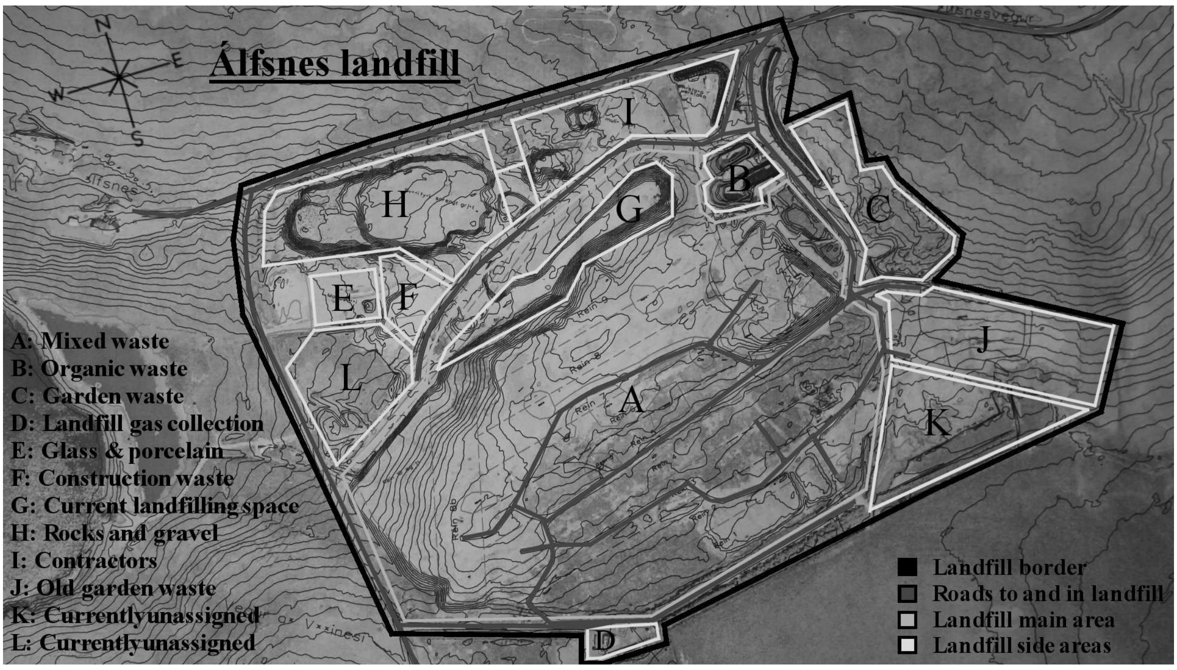


Figure 4. Álfsnes landfill layout and landfilling locations of different waste fractions (SORPA 2013a).

SORPA (2013a) has implemented the so called “Odor project” at Àlfsnes as a residential area has been built to the neighborhood of the landfill over the years and strong odors have been occasionally emitted to the surrounding area. Some measures have been taken in order to reduce the dispersal of odors from the landfill to Leirvogstunga residential area (SORPA 2013a). The goal of the new procedure is to have a better control of the amount of landfilled malodorant waste, to change the composition of malodorant waste to less odor inducing, to change the arrangement of baled waste landfilling and to spray odor-retardant to waste as a general rule. Odor reduction measures are carried out every day during the summer when the average temperature is higher in Iceland. Odors from solid waste have decreased significantly since 2012 when a covered tank for organic waste was taken into use (SORPA 2013a).

In order to meet the standards set by EEA in national waste management, SORPA has proposed an implementation of a new composting station for biogas and organic fertilizer production using mixed organic waste as a fuel from the entire GRA. Designed capacity of the station is aimed to be 30,000 tonnes of mixed organic waste per year and it is a large step towards the year 2020 goal of discontinuing the landfilling of organic waste in Iceland (SORPA 2013c). The composting station will be comprised of closed and ventilated spaces separated to reception and treatment sections and based on a three-phase process which uses separate batches to continuously treat the organic waste by hydrolysis, methane production pool and composting (SORPA 2013c). After the implementation of the composting station, SORPA has a goal to bury less than 6% of organic waste at Àlfsnes before the 2020 deadline (SORPA 2013a). This would most likely have a positive influence in overall landfill quality and it is expected to reduce air pollution from open-pit landfilling of organic waste (SORPA 2013c).

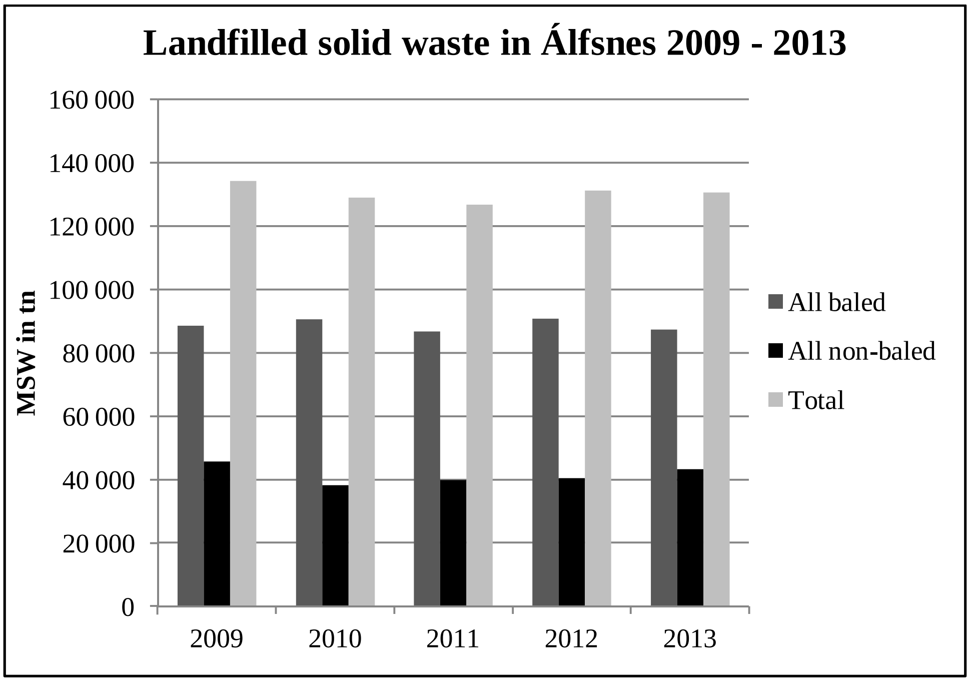


Figure 5. The distribution of baled and unbaled solid waste landfilled in Álfsnes from 2009 to 2013 (SORPA 2013a). Baled waste is MSW collected around GRA and baled at Gufunes Baling & sorting plant. Non-baled waste corresponds to waste which is unfit for baling or directly brought to Álfsnes.

Waste quantity has not increased drastically over the last five years (Figure 5) and it is positive for SORPA that neither the baled or non-baled waste quantity has increased significantly even though the population in SORPA’s waste collection jurisdiction has slowly risen (SORPA 2013a). The total amount of waste handled annually by SORPA is naturally higher than what goes to Álfsnes. In 2012, total processed waste amount was 153,783 tonnes which is about 15% more than the amount delivered to the landfill (SORPA 2013a). Variation in the MSW quantity between the municipalities of GRA is based on the amount of residents living in the area but the collected MSW content is generally very similar with only a few exceptions (Table 2).

Table 2. General composition of collected MSW in relative percentages out of 100% by from the municipalities of Greater Reykjavík in 2012. Top column abbreviations from left to right: Reyk = Reykjavík, Kóp = Kópavogur, Hafn = Hafnafjördur, Garð = Garðabær, Mos = Mosfellsbær, Selt = Seltjarnarnes, Álf = Álftanes. (SORPA 2013d).

Waste type	Reyk	Kóp	Hafn	Garð	Mos	Selt	Álf	Average
P&P	19.7%	18.0%	24.0%	23.8%	16.7%	18.9%	25.3%	20.9%
Plastic	17.3%	18.3%	17.1%	16.6%	21.3%	20.3%	21.8%	19.0%
Deposit items	1.6%	1.2%	3.1%	1.0%	0.6%	0.6%	0.4%	1.2%
Fabric	2.3%	2.9%	1.9%	1.3%	3.9%	3.8%	1.6%	2.5%
Candles	0.2%	0.1%	0.3%	0.2%	0.1%	0.1%	0.0%	0.2%
Metals	3.2%	2.7%	2.2%	3.2%	2.2%	3.6%	5.1%	3.2%
Minerals & glass	6.8%	5.9%	3.6%	2.4%	6.7%	5.1%	4.6%	5.0%
Timber	1.1%	0.5%	0.4%	0.3%	0.1%	0.5%	1.3%	0.6%
Kitchen waste	38.4%	36.2%	42.6%	37.5%	34.5%	40.2%	34.8%	37.7%
Garden waste	0.8%	0.8%	0.6%	4.8%	0.0%	0.0%	0.0%	1.0%
Hazardous/electr.	1.3%	1.1%	1.1%	4.8%	3.0%	1.2%	0.6%	1.9%
Diapers	6.2%	12.3%	3.0%	4.1%	10.8%	5.6%	4.3%	6.6%
Rubber/litter	1.1%	0.2%	0.1%	0.1%	0.1%	0.1%	0.2%	0.3%
Organic waste	69.6%	70.8%	72.6%	71.8%	66.0%	69.1%	67.4%	69.6%
Inorganic waste	30.4%	29.2%	27.4%	28.2%	34.0%	30.9%	32.6%	30.4%

3.5 Data acquisition and utilization

Data acquisition process at SORPA is a simple input – output system based on a computerized data collection. The company is obligated by EU regulations to find out the origin of waste to have a better control of what is taken to Álfsnes landfill and to maximize the sorting of waste fractions that can be either recycled or need to be treated further on elsewhere (SORPA 2013a). From the very beginning of the life-cycle of waste, SORPA keeps track on how much waste is collected around the municipalities. After collecting solid waste, it is sorted, baled and transported to Álfsnes (SORPA 2013a).

SORPA weighs all waste entering the landfill with a heavy-duty scale located in the entrance area (next to the field B in Figure 4). The scale is the main tool for acquiring information about waste quantity and quality, as in what type and how much of waste enters the landfill. The computer system saves the waste data using a manual input method where the scale access time, date, waste type and weight of waste are all recorded (Figure 6). Based on the type, origin and destination of waste, each entry in the scale gets a 10-

digit recognition code for easier processing in SORPA's database (SORPA 2013a). The recognition code, e.g. 1210119950 (which is also the most typical code corresponding to baled waste) is formed from a starting number (1), destination number for landfilling of waste (21), waste type (01), code for book keeping (19), code for landfilled waste (95) and null code (0) in the end. Each waste category has their unique, designated codes and new categories for the scale are added every year whenever it is necessary. Later on the waste acquisition codes are utilized for various purposes such as when an annual waste report is compiled or when the fluctuations in waste characteristics over a certain time period are compared (SORPA 2013a).

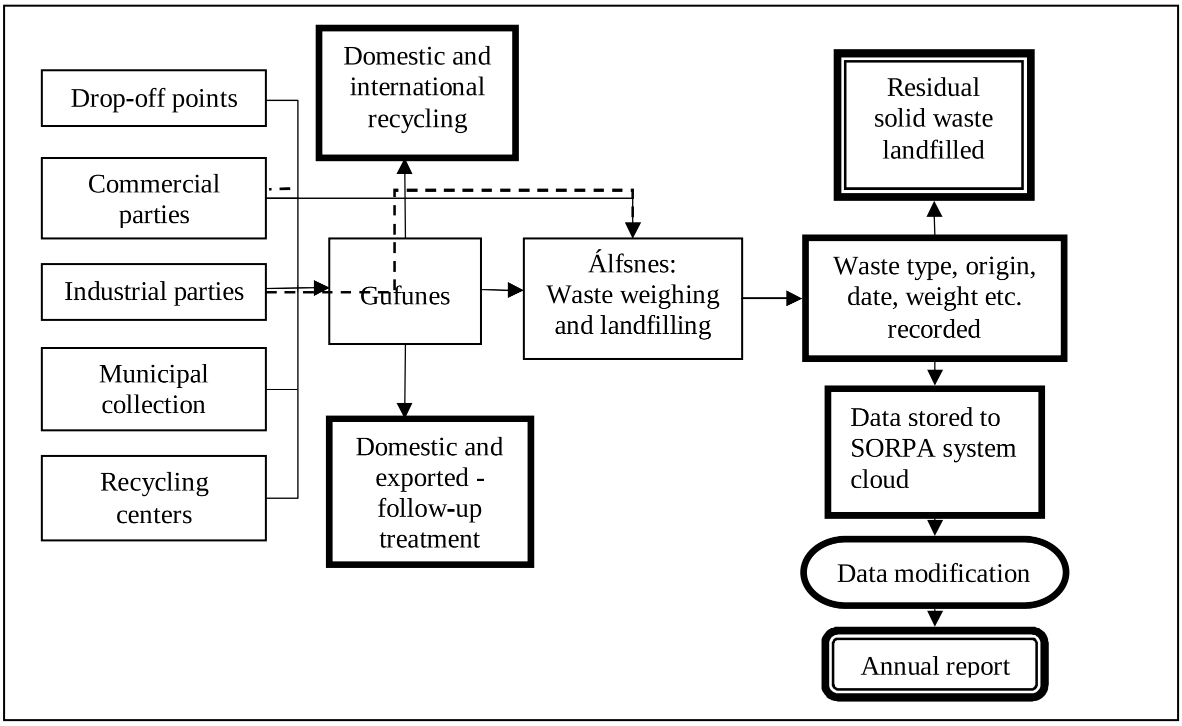


Figure 6. Waste and data acquisition route at SORPA (SORPA 2013a).

Typical amount of scale entries in a day is 30 – 40 which equals to 150 – 300 tonnes of solid waste every day. The figure varies according to the season and busier days can have up to 100 entries which is a lot of landfilled solid waste. The waste weighing data from 2012 – 2013 (Table 3) is compiled originally from two excel files provided by SORPA which both contained more than 100.000 separate scale entries usually in the range of 50 to 35.000 kilograms with approximately 65 different input descriptions. Many of the written descriptions were duplicates so they were combined to a total of 35 entries.

Table 3. The waste distribution by category, type and quantity in tonnes landfilled to Álfsnes in 2012 and 2013. Baled MSW is the largest individual fraction (SORPA 2013d).

		Product Name	2012	2013	change/%
Organic content	**Mixed**	*Baled waste (MSW, sorted)*	90734.6	87549.1	-3.5
		Contaminated soil	544.8	609.1	11.8
		Packaged food (sorted)	607.6	482.4	-20.6
		Non-baled waste (recycled, all sources)	2266.4	1987.1	-14.1
	Separated streams	Animal feed & flour	194.8	423.6	117.5
		Animal carcasses (all sources)	830.7	900.5	8.4
		Dough (wheat)	268.7	281.7	4.9
		Fish pulp oil	1672.6	2141.7	28.0
		Fish waste	712.7	821	15.2
		Horse and pig manure	325.9	218.9	-48.8
		Slaughterhouse waste (all sources)	3731.1	3426.7	-8.2
	Others	Carving waste (industrial) >50% dm	1062.3	1022	-3.8
		Sewage (sewer cleaning) 20-50% dm	27.3	195.7	615.0
		Sludge / mud 20-50% & >50% dm	3115.3	3285.7	5.5
Garden waste		Branches	2436.2	1891.3	-22.4
		Excavated soil	527	499.8	-5.2
		Grass, hay and garden waste	4100.2	4650.4	13.4
		Sawdust (lumber mills and industry)	56.4	49.7	-11.8
		Stained wood shavings 90% <180mm	400.9	20.8	-94.8
Inerts		Ash	677.8	1468.1	116.6
		Car waste (other than metal or tires)	x	50.2	x
		Glass packaging and glass containers	4258.3	4571.5	7.4
		Minerals (all sources)	6718.2	7750.2	15.4
		Plaster and plasterboard waste	437.6	538.9	23.2
Energy recoverable		Darken wood chip	1946.6	1293.4	-33.6
		Net, trawl and cables from fisheries	411.1	361.3	-12.1
		Painting waste 20-50% & 0<50% dm	58	128.9	122.3
		Rubber waste (all sources)	208	142	-31.8
		Trampling from demolition vehicles	2750.9	3695.7	34.3
Hazardous		Asbestos (all sources)	30.3	103.92	242.5
		Drugs (low latency)	3.8	10.1	165.3
		Total	133124.64	132585.23	-0.4

3.6 Gufunes waste sampling

The contents of household waste from the municipalities under SORPA's jurisdiction are examined annually at Gufunes plant to monitor possible changes in the waste composition and quality over the year. Household waste study is done in the supervision of quality manager and it was first conducted in 1993, followed by 1996 inspection and from 1999 annually in the end of each year. The purpose of the study is to examine the composition of mixed waste from households and similar waste operators in GRA. The study is a part of SORPA's compliance to EU regulation about the origin and traceability of municipal solid waste. Authorities of Gufunes plant ensure that the sample of the study reflects the origin of waste treated normally in the plant and that the study proceeds in predestined and safe manner. Classification for the studied waste is also predefined to make the actual implementation of the study more straight-forward (SORPA 2013b).

The waste sample for the study is designed to ideally reflect the origin of waste and to gain a better understanding of what is landfilled in Álfsnes. Over the years the study has been improved by adding more distinguishable waste fractions to correct the characterization of waste for more reliable results. The study is conducted by first collecting one waste sample from each waste collection district of GRA; Reykjavík, Kópavogur, Mosfellsbær, Garðabær, Seltjarnarnes, Álftanes and Hafnarfjörður respectively. Samples are taken from each district's solid waste deposits. To make the study correspond the average waste composition over the year, mixed waste is also collected from several collaborating locations in GRA, such as from green houses and individual waste containers in the region. Some samples are also taken from municipal solid waste brought to SORPA by industrial and commercial parties (SORPA 2013b).

When required amount of samples is collected and brought to Gufunes plant, mixed waste samples are first taken out of a car from a specific location in randomized order. Selected waste is then dumped to a 600 liter container for scaling and moved to the inspection table where all the present waste fractions are sorted to smaller labeled and weighted containers. A team of several people sort the waste to small containers and whole process is documented by supervising authority to ensure an accurate execution of the study (SORPA 2013b).

The resulting data from the study is taken to SORPA's digital system storage, Environment and Education. Data from the household waste study is compared to the existing data and used for statistics to improve the current waste management system further since the study reflects effectively the type of municipal solid waste which SORPA is dealing with every day (SORPA 2013b). Gufunes household waste study shows a typical distribution and percentages of different household waste fractions, while the most abundant waste fractions were P&P, plastic and kitchen waste in 2012 (Annex 1). In 2012 the study consisted of 29 different fractions, whereas 2011 study had 20% more of fractions which had to be labeled just as plain “waste”. Different shades in the table refer to the way SORPA distinguishes waste categories throughout the system including drop-off points and smaller waste collection sites (SORPA 2013b).

4 METHODS

4.1 State of the art

If the best affordable and suitable technology would be available for application to SORPA’s current facilities and processes to divert solid waste from the landfill, choosing correct methods could be set up by using various emphases. Based on the needs identified in the waste management setup, goals set by the community must be economically realistic and technically achievable (Sasikumar & Krishna 2009). Therefore, especially large scale investments for waste management should not be considered lightly and all the possibilities should be carefully evaluated.

Waste diversion can be approached for example by concentrating to economical or environmental features (Tchobanoglous & Kreith 2002). Apart from zero-waste policies which have been attempted in some countries (Scharff 2014), there is always some input to final disposal as it is beyond possible to make use of all generated waste. Gross economical and environmental benefits in waste management are also often difficult to distinguish as a lot of resources are used for implementation and maintenance activities alone (Calvo et al. 2007). This state of the art chapter is considered fictional and only to give an idea what could be done without economical restraints. The result of this scenario should be considered beneficial only in the long run. Waste fractions like hazardous waste or larger scrap metal are excluded here since they are not brought to Álfsnes landfill anyway in normal conditions.

In the environmentally friendly waste diversion approach, solid waste treatment and waste collection route should be as short as possible to reduce expenses from transportation. It would best for the general waste management to sort the MSW where it is produced (Sasikumar & Krishna 2009). Waste fractions other than MSW could be delivered directly to Álfsnes after confirming the type, amount and purity. Shorter delivery routes generate less cost since the waste transportation is one of the most expensive features of waste management in municipalities (Moliis et al. 2012). GRA has c. 84.000 households (SORPA 2013a) which should be capable of sorting their own waste before waste is collected and delivered to Gufunes plant. Sorting could also be conducted by using several collection containers to make waste sorting easier. Later on, citizens would be able to take the uncollectable but otherwise sorted and recyclable waste to any of the several drop-off points around the capital region. This would be desirable especially for metal as only 58% of the assumed metals in MSW are estimated to be recovered at Gufunes plant (SORPA 2013a). Household waste separation could be also arranged by using trash bags of different colors for different waste fractions to utilize optical sensors to sort recyclable waste at Gufunes plant.

Planned biogas and composting station to Álfsnes would then be capable of handling the majority of biodegradable waste generated in GRA which equals at most to the planned 30.000 tonnes maximum capacity of the station. Collection of organic waste could be arranged to reasonable interval, e.g. twice a month or about 24 to 36 times a year. Naturally the founding input for the biogas and composting station would not be environmentally sustainable solution but reducing biodegradable content from MSW would revoke a substantial amount of CO_2 and methane gas emissions from the landfill in the long run (Themelis & Ulloa 2006). Sorting and collecting the organic waste separately would also decrease the moisture and bad odors in the landfill (Williams 2005) which would improve the overall quality of the landfill. Encouraging citizens to build their own household composting boxes for organic waste and garden residue would slightly cut the organic waste build-up before collection. Despite the household composting, steady organic waste flow would still be guaranteed as several industry operators like slaughter houses and fisheries would still be bringing their organic waste to Álfsnes throughout the year (SORPA 2013a).

In a case of cost-effective approach, the arrangement would go partially along with the environmentally friendly approach since an approach merely based on economic considerations cannot be considered as completely satisfactory in connection with waste management problems (Costi et al. 2004). Proper and well-organized source separation for MSW would improve the baling of waste and it would make investments to Gufunes plant less necessary. High-temperature incineration is an efficient waste treatment and generates heat energy for further utilization (Dezhen & Christensen 2010) but unfortunately heat energy production would be an unnecessary surplus to SORPA. Without an actual need for energy production, it can be left out from the consideration. High-temperature incineration is also known to generate greenhouse gas and particle emissions (Dezhen & Christensen 2010) so it is not in line with SORPA's interests (SORPA 2013a). The focus in waste diversion could be set to some of the most abundant waste types like P&P, metals, plastic or kitchen waste (Table 2). Public could also participate more especially in waste sorting by raising environmental awareness so that some waste fractions would be brought directly either to the landfill or for further treatment to their respective locations instead of having to collect them from municipal households.

Short and long scale goals in waste diversion would differ particularly in diversion effectiveness as some of the waste reduction actions would require more time to implement than others while the collected waste from GRA would still need to be treated in the meantime. In SORPA's case, for example, establishing and getting a biogas and fermentation plant to be fully operational would take at least a few years to complete but waste diversion for organic content could have been already implemented and used for some time before said waste could be forwarded to the plant. Minimum effective monitoring period for waste diversion is usually a year since seasonal changes may occur (Sasikumar & Krishna 2009).

4.2 Data analysis

4.2.1 Setup and system boundaries

Waste or landfill diversion by definition is any method that prevents solid waste from being landfilled (Sasikumar & Krishna 2009). SORPA is planning to divert some of the solid waste streams brought to Álfsnes landfill in the future (SORPA 2013a) and for that purpose this thesis is searching a proactive solution to aid SORPA to improve its local and regional waste management. The first criterion in waste diversion is set to SORPA's preferred methods like recycling and energy recovery, as e.g. using incineration is not environmentally sustainable or pollution reducing treatment and not in line with SORPA's interests (SORPA 2013a). The second criterion for waste diversion is to use abundant or recyclable waste fractions like P&P, plastic and kitchen waste (SORPA 2013a). Diverting solid waste from Álfsnes is bound to improve the waste management not only on local scale but later on also on regional and national level as SORPA is handling solid waste from the whole GRA which is the waste generated by approximately 63% of the population of Iceland (SORPA 2013a).

Waste diversion in this context equals to waste ending up anywhere else but into the landfill by any means available (Table 4). Whether waste is recycled, exported for further treatment or treated in a biogas and fermenting plant inside the landfill perimeters, the final destination is still other than the permanent disposal in the mound. Diverting waste from the landfill will naturally gather it somewhere else, e.g. recycled plastic will end up either to domestic handling or it will need to be taken abroad for further treatment but any diverted waste contributes to decreased burden in Álfsnes. From the three different waste sources of Álfsnes, municipal waste is collected by third-party organizations and sorted at Gufunes, whereas industrial and commercial waste is either brought directly to the landfill or to Gufunes plant and then sorted and baled so the residual waste can be delivered to Álfsnes (SORPA 2013a). All inputs result to potential waste diversion locations, from consumers and citizens to the endpoint at Álfsnes.

Table 4. The most typical waste diversion methods utilized in municipal waste management (Sasikumar & Krishna 2009). All of the listed methods except waste minimization are applicable to SORPA's facilities, but combustion and incineration are not preferred (SORPA 2013a) and will be thus excluded from the analysis.

	Reduction method
Waste diversion	waste minimization
	source reduction
	re-use
	recycling
	composting
	energy recovery
	combustion
	incineration

Until the improvements I propose in this thesis will or will not take effect, the population of the capital region is assumed to stay generally same as in the time of writing this thesis. By UAA's estimation (2002), the most notable population rise will continue in the capital region and it will inevitably increase the need for a more efficient waste management too. I will assume that the collected waste quality is the same for all the evaluated alternatives in the analysis, just like the waste quantity is assumed to be on a same level as it has been for the last couple of years in GRA (Figure 5). General waste composition, household structure and waste quantity inside the waste collection jurisdiction and the landfill gas collection of Álfsnes are the same in all the evaluated alternatives. Landfill gas collection pipes would be additionally extended to the newer parts of the landfill mound whenever necessary in all alternatives. Real-life data from SORPA is used for the data analysis.

To my knowledge, SORPA does not have any major changes in sight for the future waste management in GRA except for the biogas and fermenting plant which would expectedly improve the organic waste treatment towards national goals (SORPA 2013c). Currently the majority of waste delivered to Álfsnes is landfilled and a lot of potentially exploitable material is rendered useless. Optimal future scenario would have less input to and more outputs from the landfill if possible. It is expected that a lower waste input will lead to a decrease in output quantity as well but out of the current three inputs (Figure 3), the most notable long-term influence would be to the methane gas generation (Themelis & Ulloa 2006) as compost is made from garden waste and rocks and gravel are available almost at all times. The energy used in the exchange of waste from starting point to the landfill like electricity, consumables or vehicle fuel are not covered in the analysis except for the waste diversion impact on traffic where distances and overall usage of collection vehicles might be compared roughly.

4.2.2 Analysis tool selection

In order to meet the challenges of climate change and other environmental threats, environmental considerations have to be integrated into a number of different types of decisions made both by businesses, individuals, public administrations and policymakers. Information on environmental aspects of different systems is needed, like in the case of this study, and many tools and indicators for assessing and benchmarking environmental impacts of different systems have been developed (Finnveden et al. 2009). These tools include Life Cycle Assessment (LCA), Environmental Impact Assessment (EIA), Cost-Benefit Analysis (CBA), Material Flow Analysis (MFA), and Multiple Criteria Decision Analysis (MCDA) along with many others (Finnveden et al. 2009).

The goal of this thesis is to search for alternatives to improve solid waste landfilling as a proactive solution by diverting solid waste from Álfsnes landfill but a complete analysis of the landfill in question is not required. For instance, Life Cycle Assessment is a tool to assess the potential environmental impacts and resources used throughout a life-cycle of a product, i.e., from raw material acquisition, via production and use phases to waste management (Finnveden et al. 2009). Going to an extent of LCA would be questionable as the planning of proactive waste diversion from the landfill is only covering the system partially, whereas LCA studies the whole life-cycle of a product, system or process in four separate phases (Rebitzer et al. 2004).

Selected analysis tool should be able to make use of the waste data provided by SORPA. Available data includes the landfilled waste quantities from 2012 – 2013, waste types by category, some dispersed price figures of landfilled waste, dates for landfilling, the future prospects of SORPA, a rough estimation of upcoming changes in population dynamics of GRA, volume limitation information for the landfill and SORPA's points of interest in waste diversion (SORPA 2013a). It is difficult to derive a reliable plan for waste diversion by judging the available information alone and therefore an assisting tool is required.

An analysis tool should utilize the provided data as much as possible to evaluate the future development of SORPA’s waste management compared to the current setup. Setting the emphasis to the characteristics of previously landfilled solid waste is only logical since the main point of the thesis is about solid waste diversion from a landfill. Therefore I have decided that the previous waste collection data has a top priority in importance while choosing the analysis tool. Waste collection and landfilling data can also work as a potential indicator to forecast the future waste development in GRA.

In order to choose an analyzing tool for this study, capabilities of various tools have to be reviewed shortly. LCA and its similar applications like Life-Cycle Inventory Analysis (LCIA) or Environmental Impact Assessment (EIA) are too wide as they consider all attributes or aspects of natural environment (Pennington et al. 2004), human health and resources (Finnveden et al. 2009). Cost-Benefit Analysis and Material Flow Analysis are not suited either, CBA for being a more straightforward method concentrating on economical data (Begum et al. 2006) which is insufficient in this study and MFA not fitting the scope of this study (Finnveden et al. 2009). Multiple-criteria decision analysis (MCDA) is useful in order to select the best solution for improvement out of several alternatives (De Felice et al. 2013). It also covers environmental and socio-economic features and can manage complex data with multiple variants. However, a full-scale MCDA would be so wide that the available real-life data in this study is not sufficient to produce a proper analysis, not to mention that it is typically conducted by a group of professionals or specialists who work the tool together for a reliable and plausible result (De Felice et al. 2013). Such extent is out of the question considering the available time and resources in hand.

A few applications based on MCDA using the same general principle exist (Tsafarakis et al. 2010). One of them is ARVI, a tool designed for multiple criteria assessment of impact significance (IMPERIA 2014) meaning that it can estimate how important the impacts in examined case really are. ARVI would be applicable in this study as one approach to estimate the points for improvement in solid waste management system is to assess the impacts of the system to social and socio-economic environment and nature (Sasikumar & Krishna 2009). Considering the scope and time limitation of this work, it is best to use a tool to evaluate which factors are the most significant for a proactive waste diversion and complete the analysis by filling in suggestions to each individual case which the tool is unable to add. I have chosen to use ARVI to clarify the abovementioned factors. After the execution of ARVI analysis, it will be possible to give a more reliable estimation of how much and to what extent solid waste could be diverted.

4.2.3 ARVI analysis tool

ARVI is an excel-based tool developed in the IMPERIA project (2014) for managing an impact significance assessment in environmental impact assessment projects like LCA or EIA. The tool can be used to gather and manage the impact assessments in one place and to create visual results for impact assessment. It is based on multiple criteria decision analysis (MCDA) and the developer team consists of several entities in Finland (ARVI 2014).

ARVI is more of a helping tool than an independent tool for decision making. It is designed for supporting a decision-making process and to give a better perspective of what kind of impacts a planned project can have to different factors in any studied case. Tool is still in development (2014) and it has not been tested yet to be suitable for every possible scenario in environmental research. Especially in terms of applicability it is likely to have some minor issues but I have confirmed that ARVI is suitable for this thesis and data in hand due to the availability, flexibility and support from the developer team of ARVI. Tool will be used prior to a more detailed evaluation of waste diversion from Álfsnes.

A typical ARVI analysis measures the impact of some anthropogenic activity to the nature and social or socioeconomic environment. Depending on the desired emphasis of the study, evaluated impacts in ARVI can be set up very distinctively to cover e.g. water, soil, birds and mammals or to cover larger entities like lakes, abiotic factors or simply the entire climate. ARVI supports a simultaneous evaluation from one to multiple alternatives for any studied case. This means that the same measured impacts can be made to apply to each evaluated alternative while they are still weighed differently based on the goal of each alternative (ARVI 2014).

ARVI tool evaluates the characteristics of inputted impacts in several ways. ARVI is split to two different sections. First section covers the impact assessment where the chosen impacts are evaluated by their sensitivity, magnitude and significance. Sensitivity consists of three parts: existing regulations and guidance (identical for most parts in the analysis), societal value and vulnerability for changes. Magnitude consists of intensity and direction, spatial extent and duration but the significance of impacts is evaluated alone. Significance of each impact is evaluated by their estimated importance for each alternative. Second section of ARVI covers a detailed Reasoning-sheet for estimated impacts and there is also a tab reserved for possible mitigation measures and impacts which are not included in the actual analysis (ARVI 2014).

4.2.4 Analysis tool implementation

Evaluating too many alternatives or impacts for waste diversion from Álfsnes would have been time consuming and result into bias in decision-making. To maximize the benefit over time, I have decided to assess a total of 4 alternatives. The alternatives are the current landfill setup (1.), cost-effective (2.), environmentally friendly (3.) and balanced alternative (4.). Usually using simple trade-offs between economical and environmental objectives is difficult and results into using a multi-objective framework to consider the waste management problem (Robba et al. 2008) but I have decided to try all three approaches in the analysis. Current setup is used as a reference to new alternatives and compared to the new, improved alternatives later in the thesis. Cost-effective alternative is searching for a more affordable solution to the current waste management, environmentally friendly alternative disregards cost-effectiveness by attempting to minimize environmental impact of solid waste landfilling and finally, balanced alternative is striving to combine the best features of two previously suggested alternatives.

The objective of ARVI analysis in this thesis is to support the decision making process and define suitable waste treatment methods for the evaluated alternatives to improve waste diversion from Álfsnes. ARVI measures the impact of features that are influencing the landfilling of solid waste in Álfsnes. Evaluated impacts are chosen in such a way that comparing the alternatives with each other should point out the sought differences, e.g. cost-effective approach should obviously have a smaller impact on affordability than environmentally friendly approach where the focus is not set to economical aspects. Small impact on affordability equals to more affordable waste management and is likely to eventually spare resources.

ARVI analysis will mainly focus to impacts in social and socio-economic environment and will only cover the landfill area except for the impact on employment, traffic, public acceptance; climate and level of change required (Table 5) which have been extended to cover also the supporting functions of Álfsnes. All the impacts chosen for the analysis are described in Table 5. As for the environmental impacts, no sufficient data was available to accurately estimate the impact of the landfill to ground water, climate, animal populations or aesthetic outlook. Literature can only work as general reference (Calvo et al. 2007) since there is no real-time data for comparison. It would be possible to give a vague estimation of leachate flow or greenhouse gas emissions to atmosphere based on the size of the landfill but the estimated impacts would be generally identical for all the alternatives making it difficult to make any comparison. Only brief written information was available about odor emissions and leachate treatment in Álfsnes which was covered in chapters 3.4 and 2.3 earlier in the text. It is simplest to exclude any uncertain impacts from ARVI analysis and refer to some of the uncovered features later in the results and discussion if necessary. The three remaining environmental impacts (Table 5) are mostly based on literature like the impacts affiliated with economical features.

Impacts are chosen to ARVI to represent some of the main features affiliated with the landfill and to give a reasonable and noteworthy basis to compare and make a distinction between the proposed new alternatives from each other. ARVI defines how far each evaluated impact extends and no separate briefing on that account will be necessary. As the initiative for the planned biogas and fermenting plant has already been taken at SORPA, it is taken into an account in each alternative including the current setup and will be considered as one of the diversion point for biodegradable waste whether or not the conclusion of this thesis will result into any real-time actions.

Table 5. Examined impacts to nature, social and socio-economic environment in ARVI and their descriptions in short (ARVI 2014).

Category	Impact	Impact description
Nature	Environmental stress	How the surrounding environment of the landfill is estimated to react from changes in a proposed alternative.
	Climate and air quality	How climate and air quality are affected by actions taken in a proposed alternative.
	Water systems	How surrounding water system: sea and ground water would be affected by the actions taken in a proposed alternative.
Social and socio-economic environment	Affordability	How realistic the alternative and its proposed changes comparing to the current landfill setup are estimated to be in economical terms.
	Applicability and technical potency	How applicable the approach of an alternative is estimated to be considering its technicality and implementation requirements.
	Maintainability	How controllable the approach of an alternative would be in the near future to maintain the same quality and continuity of the waste management.
	Waste availability	How available solid waste would be for utilization around the year in a proposed alternative.
	Public acceptance	How the public is estimated to react upon the changes proposed in an alternative for waste management. Public, especially municipal households and small businesses can hold a key to successful waste diversion.
	Level of change required	An estimation of how much change in the existing system is required to implement the changes in a proposed alternative.
	Landfill outputs	How much the alternative would produce beneficial byproducts at the landfill in comparison to the current setup.
	Living conditions	The impact to the quality of life in residential areas near the landfill.
	Traffic	The impact to the traffic into, at and out of the landfill.
	Employment	The impact to employment at SORPA. More waste management activity would require more employees whereas more unified and simplified actions would save working hours.
	Land use	The impact to land use in the landfilling.
	Landscape	The impact to landscape by increased or decreased land use and landscaping of occupied space.

5 RESULTS

5.1 Comparison of alternatives using ARVI

5.1.1 Current landfilling setup

The current setup of Álfsnes landfill and its supporting functions (Gufunes, drop-off points and the waste collection network of GRA) served as a reference case for the three new assessed alternatives in ARVI analysis. The evaluation of impacts (Table 5) and their attributes sensitivity, magnitude and significance (Annex 2 – 5) in the analysis were based on my personal evaluation, literature and the data (2013) from the solid waste landfilling and current operations of SORPA.

Current setup has been proven functional and effective over the course of last couple of years in GRA and the planned biogas and fermenting plant (SORPA 2013c) will surely keep improving the system onwards. The key factor to waste diversion in future would most likely be in improved waste separation with SORPA's preferred methods as it seems that there are several waste fractions in MSW (Table 1) that are standing out more than the others. Positively for the reserved landfilling space, waste quantity received at Álfsnes has not risen in few years (Figure 5) but the demand for landfilling will still increase due to population rise (UAA 2002).

Current outputs of Álfsnes are purified methane gas, compost and rocks (SORPA 2013a) and if a sufficient sanitary level will be achieved, planned biogas and fermenting plant will be providing organic fertilizer and compost up to commercial purposes in a few years as a by-product from the extended methane gas production (SORPA 2013c). Landfill gas collection should remain as it is and be expanded to the newer parts of the landfill in time as the gas generation in the mound will remain generally same for the time being even if the gas would not be collected. This applies to all new assessed alternatives as well.

5.1.2 Cost-effective alternative

Cost-effective alternative assessment in ARVI was based on the minimum financial input and exploitation of existing functions of SORPA. The goal of this alternative is to achieve the highest economical benefit on a reasonable scale from solid waste landfilling while still reaching for environmentally sound activities. The reasonable scale refers to an extent of measures that are possible to carry out without major investments while retaining the functionality of solid waste management at SORPA. Cost-effectiveness in this alternative refers to making improvements to the existing system with preferably low costs and saving in expenses by means of waste diversion as less landfilled waste equals to less required waste treatment. Net expenses from waste diversion are not taken into account.

Public is expected to have a greater role contributing for waste diversion, whereas environmental features have been left for lesser attention on purpose. Cost-effectiveness is brought on by household waste separation, making use of some separately collected waste fractions, possibly altering the waste pick-up schedule, mixing biodegradable waste with dry waste to decrease the moisture and taking an advantage of existing base of waste collection locations like drop-off points and larger garbage bins in GRA.

5.1.3 Environmentally friendly alternative

Environmentally friendly approach concentrates less to the economical factors (Table 6) and gives some suggestions for how to achieve an environmentally beneficial goal. The goal of this alternative is to decrease the environmental impact of solid waste landfilling in Álfsnes by diverting some of the more abundant waste fractions like kitchen waste (covered in chapter 3.3.), possibly increasing landfill output and concentrating more to overall environmental impact of the landfill. This alternative implies also that continued landfilling of inert waste is more acceptable than landfilling for example organic waste or hazardous materials (Williams 2005) even though landfilling is not an environmentally friendly solution to begin with. Positive impact to environment is considered achievable from waste diversion which reduces the environmental burden in the landfill and decreases any further possibility of environmental damage from landfilling solid waste. Net environmental impact from all the activities carried out in SORPA’s facilities is not taken into account due to the limited time and data in hand and the scope of this thesis.

A large emphasis on waste diversion of Iceland has already been put to biodegradable waste due to EU’s Landfill Directive (1999/31/EC). Apart from biodegradable waste, this alternative concentrates on diverting efficiently some waste fractions from MSW while making a use of separate waste flows. Possible investments I propose here are expected to be the largest out of all evaluated alternatives. This alternative does not take into account the real costs affiliated with exporting waste or transporting it elsewhere for further treatment. Benefit is calculated from the net waste amount diverted from Álfsnes comparing to the waste amount that would be landfilled if no waste diversion measures would be taken. If less waste will be taken to the landfill, it means also that less traffic will be needed and thus the environmental impact will be even smaller than before.

5.1.4 Balanced alternative

The last of the three new assessed alternatives was assumed to have the highest resemblance to the current setup of Álfsnes landfill. The name of the alternative refers to the goal of searching an intermediate solution between cost-effective and environmentally friendly alternative, taking the most beneficial and applicable parts of both approaches into consideration and combining them into a working system while still making some improvements compared to the current setup.

As stated above in the description of current setup and two new alternatives before this, all the same rules are applied to this case as well.

5.2 ARVI analysis results

ARVI analysis produced a number of charts for visual inspection and most importantly for this thesis it provided the impact assessment and reasoning sheets (Annex 2 – 9) and an impact significance chart (Table 6) to compare the new alternatives with the current setup of Álfsnes. Impact assessment sheets show how I have weighted the impacts for each alternative and reasoning sheets show where the decisions were based on. Finally the impact significance chart (Annex 10) defines how important each impact is estimated to be for an alternative and to what direction evaluated impact will shift if a proposed alternative takes place. While the impact significance table does not give any suggestions on how to achieve the goal of an alternative, it shows clearly how the landfill is estimated to respond to the changes.

Table 6. The impact significance chart of alternatives evaluated in ARVI analysis. The significance of impacts in each alternative is estimated on a scale from negative (----) to positive (++++) in comparison to the current landfilling setup (ARVI 2014).

Impact Significance

Impact	Current setup	Cost-effective alternative	Environmentally friendly alternative	Balanced alternative
Environmental stress	+	+	+ + +	+ +
Climate and air quality	+ +	–	+ + +	+ +
Water systems	+ +	–	+ + +	+ +
Affordability	–	+ + +	–	+ +
Applicability and Technical potency	+	–	– –	–
Maintainability	+	+ +	–	+ +
Waste availability	+	–	+	+
Public acceptance	+ +	+	+ +	+
Level of change required		+ +	–	+
Landfill outputs	+	+ +	+ + +	+ +
Living conditions	+	–	+ + +	+ +
Traffic	–	+	+ +	+
Employment	+	+ +	–	+
Land use	–	+	+ +	+
Landscape	–	–	+ +	+

5.3. Improved waste diversion methods for new alternatives

5.3.1 Preconditions for improved waste diversion at Álfsnes

All of the suggestions I present in chapters 5.3.1 – 5.3.5 are intended to replace only the waste management functions in question, e.g. increased household waste sorting and collection would replace the current arrangement SORPA is applying to municipal households. The rest of the functions and services are meant to remain as they are currently carried out. This rule applies to all of the new proposed alternatives below. Some of the suggestions might not be fully applicable yet due to the possible limitations in the waste management system. Diversion of a certain waste fraction is possible to start in any desired time but if there is not yet a way to treat or transport the waste elsewhere for processing, temporary preservation could turn out to be less favorable than landfilling the waste in the meantime.

Solid waste received annually in Álfsnes has summed up approximately to 130.000 tonnes in recent years (Figure 5). The quantity of MSW in total waste volume has varied from 70.3% of 2010 to 66% in 2013 which contributes to more than twice the amount of other received waste in the landfill (SORPA 2013a). As MSW considerably exceeds other waste in quantity, it makes sense to focus mostly on waste diversion from that quota. MSW has more variety in content than any other collected waste (Williams 2005) as waste like candle residue, cosmetics and even drugs can be found in it (Annex 1). Municipal waste consists of waste generated by households to a great extent, but may also include similar wastes generated by small businesses and public institutions and collected by the municipality; this part of municipal waste may vary from municipality to municipality (Williams 2005). These quality fluctuations along the possibility of recyclable or hazardous waste ending up to the landfill are the reason why it is important to concentrate more to collection and sorting of MSW as opposed to other waste. It is also important to remember that not all MSW is coming from municipal households. A part of MSW comes also from small businesses, municipal collection containers and trash cans around the city which means that the waste sorting instructions do not fully apply to all waste sources.

Around the year availability of a certain waste type might not be constant and sometimes a waste treatment might not be usable for the time being. This is preventable by making a temporary deposit space for certain waste types to keep the excess waste until it can be treated. Preservation might not applicable if e.g. waste is too active to be contained for extended periods like biodegradable waste or if preserving waste in a temporary container would not be economically feasible. Furthermore, from all waste that has entered Álfsnes in last couple of years, roughly 80% have been landfilled and the rest have been recycled so not all waste delivered to the landfill go simply to disposal (SORPA 2013a). When the majority of the common waste fractions entering the landfill and their respective quantities are known, it is possible to estimate how much of the waste flow would be possible to divert. Higher than 50% diversion rate is unlikely to happen fast but it is good to contrast different diversion rates by waste type (Table 7) for comparison to understand what kind of waste quantities SORPA is coping with.

Table 7. Waste characteristics of MSW and the diversion rates in 10, 20, 40, 60 and 80 % from 100% of landfilled waste in tonnes. The waste quantities are from 2012 (SORPA 2013a). Same analogy applied in this table is applicable to the data for later years as well.

2012	% of total	Weight	10 %	20 %	40 %	60 %	80 %
P&P	20.9	18963.6	1896.4	3792.7	7585.4	11378.1	15170.9
Plastic	19.0	17195.4	1719.5	3439.1	6878.2	10317.3	13756.3
Deposit cont.	1.2	1119.2	111.9	223.8	447.7	671.5	895.3
Fabric	2.5	2276.4	227.6	455.3	910.6	1365.9	1821.1
Candles	0.2	138.0	13.8	27.6	55.2	82.8	110.4
Metals	3.2	2872.3	287.2	574.5	1148.9	1723.4	2297.8
Minerals	5.0	4549.4	454.9	909.9	1819.8	2729.6	3639.5
Timber	0.6	546.3	54.6	109.3	218.5	327.8	437.1
Kitchen w.	37.7	34231.8	3423.2	6846.4	13692.7	20539.1	27385.5
Garden w.	1.0	905.2	90.5	181.0	362.1	543.1	724.1
Hazardous w.	1.9	1698.1	169.8	339.6	679.2	1018.9	1358.5
Diapers	6.6	5993.1	599.3	1198.6	2397.2	3595.9	4794.5
Rubber/litter	0.3	245.8	24.6	49.2	98.3	147.5	196.7
Total	100	90734.6	9073.5	18146.9	36293.9	54440.8	72587.7

Available solid waste for diversion is divided to collected and baled MSW and to other separately collected or received waste fractions (Table 3) in new assessed alternatives. Waste diversion can conserve a lot of space from a landfill if done correctly and it will direct potentially valuable waste like plastic (Hooper et al. 2002) where it can be utilized better as raw material or substitute materials which would otherwise be expensive or difficult to acquire. In all alternatives, a proper sorting of solid waste is a key feature to waste diversion regardless where it is carried out. Some of the features proposed in new alternatives might be overlapping as a waste treatment can be both cost-effective and environmentally friendly at the same time (Robba et al. 2008). The proposed improvements and changes to SORPA's existing system will not compromise the functionality of waste management but instead is meant to improve it. All of the suggestions presented in chapters 5.3.2 – 5.3.5 are compiled to a single table in the end of Results –chapter for quick reference (Table 8).

5.3.2 Current landfilling setup

Àlfsnes utilizes currently (Figure 7) some fees on entrance for certain waste types (SORPA 2013a) and one solution to increase the income from landfilling would be to raise the fees in question. Even a marginal raise in handling fees would bring in more money to be directed for other activities and it might indirectly increase especially the municipal household recycling if citizens would be more willing to find alternative uses or disposal locations for their waste rather than bringing it to Álfsnes. However, it is important to keep in mind that waste management is a public service (Beigl et al. 2008) and every citizen should have a right to access it without remarkable expenses. Secondly, waste disposal fees at Álfsnes and Gufunes plant entrances are related to regulations of the Recycling Fund (SORPA 2013a) so SORPA does not have the right alone to alter the fees.

The organic waste delivered to Álfsnes is estimated to remain generally same as before except for a possible slight increase in quantity in following years. Even if the proposed biogas and fermenting plant will be built (SORPA 2013a), it is an unrealistic approach to forward all biodegradable waste there. Some waste fractions, like industrial carving waste or sewage sludge do not always have the right characteristics for biogas production and for example sewage sludge has often a high possibility of containing heavy metals, pathogens and organic pollutants (Fytili & Zabaniotou 2008) which restricts the use of sludge as a landfill cover or as a part of an anaerobic digestion process. Harmful or toxic substances can be passed on to the food-chain if compost with such previous characteristics is used as an organic fertilizer (Fytili & Zabaniotou 2008). The utilization of some waste fractions from separate streams like ash, sawdust and wood chips could be studied further.

Current setup is making an active effort on treating all waste that is received both at Gufunes and Álfsnes. Without making any new investments to both locations apart from the proposed biogas and fermenting plant, increased waste diversion is still possible by waste minimization and reduction outside the facilities. The distribution of different waste types in MSW (Table 1) tells about the waste disposal habits of people in GRA. While there is an existing base of instructions for waste sorting in households, landfilling data (Table 7) indicates that especially glass and metals are abundant and still disposed to energy bin even though they could be also brought separately to drop-off points.

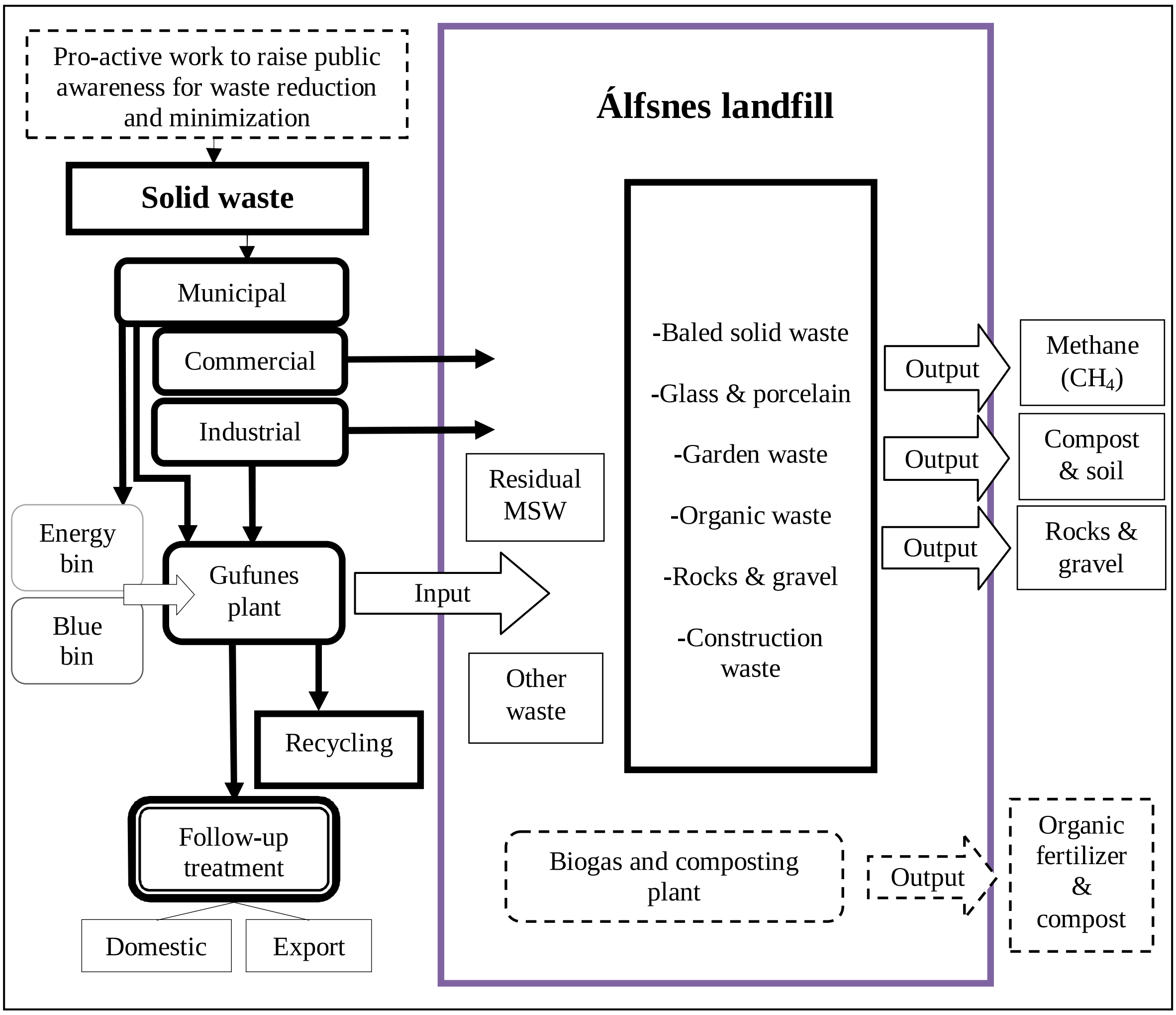


Figure 7. Current waste inputs and outputs of Álfsnes landfill site. This is the starting situation of Álfsnes landfill in the capital region for the assessment of improved future waste diversion.

5.3.3 Cost-effective alternative

Cost-effective alternative (Figure 8) aims for a gradual waste diversion starting from a minor success at first to see how the public and system responds to the changes. If the response is positive, diversion methods can be then increased. Positively municipal households are not required to make excessive investments to comply with the changes, whereas benefit is expected to be notable compared to the current setup. As I stated in the chapter 5.3.1., it is easiest to focus on diverting MSW due to its characteristics (covered in chapter 3.3.) and amount exceeding any other waste brought to Álfsnes.

Content from collected MSW (Table 7) suggests that all kinds of waste are still disposed in municipal households despite the regulations and sorting instructions provided by SORPA. Metal content in MSW could be simply addressed by banning the disposal of household metal waste such as empty food cans, wires, cables and wire coat hangers. Magnet separation at Gufunes (SORPA 2013a) has proven to work quite well but metal is still ending up to the landfill even today. In 2012 the landfilled metal quantity was a mere 3.2% (Table 7) but with the extent of waste handled at SORPA, it equals close to 3.000 tonnes which is a tremendous amount of lost potential. Diverting even 20% of that amount would make a remarkable difference in benefit.

Due to the proposition and possible implementation of the biogas and fermenting plant, biodegradable waste should be sorted in municipal households to save the effort from SORPA. While I am not suggesting a separate bin for kitchen waste, it could be collected into a separate, distinguishable bag like a yellow plastic bag which could then be recognized and sorted at Gufunes. That way the moisture in MSW would be decreased and it should also inhibit partially the generation of bad odors. In 2012, kitchen waste contributed to over 37% portion of all collected MSW which was a one third of the total waste volume that year. At first approximately 40% of kitchen waste (Table 7) could be attempted to sort and later on the diversion rate could be increased towards the goal of 100% before the year 2020 (SORPA 2013a). On top of the kitchen waste separation to energy bin in separate bags, home composting (HC) should be encouraged wherever it is possible. HC has been studied e.g. in England and approximately 20% from generated biodegradable waste has been composted in households which had a home compost box (Smith & Jasim 2009).

Plastic content in MSW coming from households can be collected using the same principle as for biodegradable waste. Collecting hard plastic packaging to another colored plastic bag like for example a green bag would make the recognition and sorting easier at Gufunes. Trash bags containing plastic could be disposed to energy bin and both the plastic and kitchen waste bags would be possible to sort either by optical method or by hand. Up to 40% of plastic waste (which is close to 7.000 tonnes) from municipal households could be attempted to sort from 2012 quantity (Table 7). While I do not have sufficient knowledge of optical waste sorting, it could be examined further. Sorting the arriving waste by hand at Gufunes would be an efficient and relatively cheap method to perform as it does not require a lot of modifications to the existing hardware but considering the daily waste quantity passed through Gufunes plant, it is better to have only as a secondary option in this alternative. Depending on the initial execution, hand-sorting of MSW can turn out to be consuming and cumbersome to the people assigned for it so it does not have the first priority as a sorting method.

The amount of drop-off points should not be reduced as they have proven to be a viable element of SORPA’s waste management in GRA (SORPA 2013a). Since the amount of bins per household will not be changed, adjusting the waste collection routes or cycles is not necessary either. Municipal households could improve waste diversion remarkably by sorting waste already in its birthplace. Having a separate bin indoors for glass, metal and other waste fractions accepted by drop-off points would save the trouble of waste sorting from SORPA. Not all the citizens have a possibility to take their sorted waste to drop-off points but there could still be more people delivering their sorted waste than what has been so far. If less waste ends up to disposal in households and small businesses, less waste would have to be transported for sorting and final disposal.

SORPA could reprise its role as an environmental educator and distribute a new waste sorting and disposal instructions to every municipal household and small business in GRA and attempt to manage the increasing waste generation by improving waste reduction in the area. While banning a lot of waste from energy bin might not be the most effective solution, encouraging citizens to sort their waste to work together towards cleaner tomorrow could change people’s attitudes to be more positive about profound sorting, recycling and waste minimization.

In addition to MSW diversion, some of the separate waste streams can be utilized in small quantities at the landfill and some other locations. Received sawdust is available for multipurpose use. Relatively dry sawdust can be used to absorb moisture from biodegradable or other organic waste and small quantities can be applied to anaerobic composting process (Pichtel 2014) or used as a bulking agent to create better compost (Zorpas & Loizidou 2008). Manufacturing combustible pellets, selling or giving clean sawdust away to farms or marketing it to cover trails to reduce erosion could also be considered. Essentially the utilization of separate waste fractions depends on their origin and purity because their potentially harmful content can be passed on to the environment (Williams 2005).

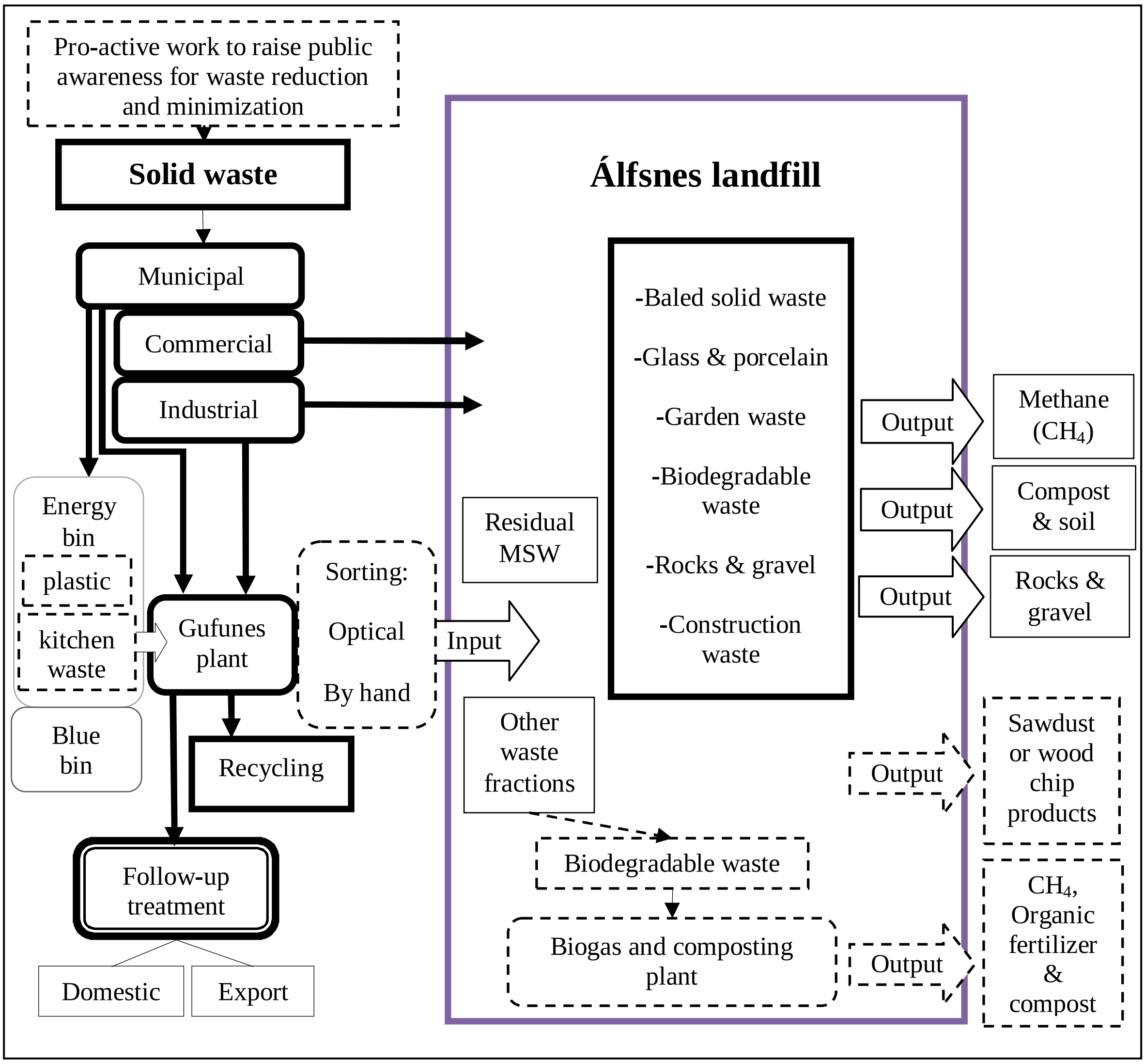


Figure 8. A summarized illustration of the proposed cost-effective alternative for landfilling of solid waste at Álfsnes with all inputs, outputs and supporting functions. Text boxes with cut-lines are the new proposed changes to the existing waste management system.

5.3.4 Environmentally friendly alternative

Environmental impact of landfilling is intended to be decreased with waste diversion. Higher waste diversion rate benefits the environment when waste is utilized as raw material elsewhere instead of ending up to permanent disposal at the landfill. Just like in the previous alternative, the most significant waste diversion in this alternative (Figure 9) is expected from MSW and separately collected waste fractions are referred only for parts that are applicable to waste diversion.

As SORPA is planning to build a biogas and fermenting plant, a decline can be expected especially in odors and other gas emissions from solid waste which are known to pose an environmental and health risk to the surroundings of a landfill (Palmiotto et al. 2014). It is likely that a part of the received biodegradable waste will be impossible to treat in the biogas plant without at least some level of pre-treatment (White et al. 1995), so this alternative concentrates on improved sorting and collection rather than to the actual treatment to divert biodegradable waste, as treatment efficiency does not depend only on waste quality but also on other features like the utilized technique, moisture and waste homogeneity (Cheremisinoff 2003). In methane gas production, all hydrolysis processes are sensitive to continuity of feedstock in quality and quantity, which makes them unsuitable for mixed wastes and more suitable for agricultural residues such as sawdust, straw, or specially grown crops (Cheremisinoff 2003) which are something that SORPA has available in separately received waste fractions (Table 5).

Apart from home composting, organic waste is difficult to divert as it cannot be recycled by itself unless it is first pretreated and turned into e.g. compost or fertilizer (Pichtel 2014). On the account of concerns over the possible unwanted odors from composting, well-treated household compost box does not produce bad smell (Smith & Jasim 2009). Citizens of municipal households of GRA should be encouraged to try HC and either buy or build their own composting boxes. Making a pamphlet to distribute around the city on how to build your own working composting box would possibly motivate people to help to decrease the burden on the landfill. While this is only possible for a limited number of citizens, even a little amount of diverted biodegradable waste would remove it from the waste flow to Álfsnes. HC has a very little environmental impact compared to the untreated landfilling of same material (Smith & Jasim 2009).

Kitchen waste collection could be done either by using a smaller insert in energy bin or using a separate 90*l* bin only for biodegradable waste. Using a separate container would benefit the waste collection since the insert would have to be removed while the energy bin is tipped over by collection vehicle. Kitchen waste collection could be then improved further by combining nearby households to gather all of their kitchen waste to a same container so that every household would not have to invest to a separate bin. Collection interval could be set to e.g. from 24 to 36 times a year or every two weeks and on a separate day from energy and blue bin (Figure 3) collection to make better use of existing hardware and to regulate the waste acquisition from different municipalities. Kitchen waste collection should be done more often during the warm summer months to prevent the generation of unwanted odors in 90*l* bins. Considering the proposed bin size, up to 60% or kitchen waste in MSW could be attempted to divert this way.

For MSW content, the most abundant waste fractions plastic, P&P, kitchen waste and metal (Table 7) would be ideal for waste diversion. Plastic waste is problematic owing to the high volume per weight ratio and is not hence an attractive material for collection and recycling. There are also economic factors associated with recycled plastics but most importantly post-consumer plastic is still suitable to be used for another new product, making it obvious why recycling plastic happens today in the first place (Ambrose et al. 2002). Plastic waste content in MSW was around 20% from collected waste quantity in 2012 (SORPA 2013a) which equals to over 17.000 tonnes of waste. By using a separate colored plastic bag in municipal households, plastic packaging could be disposed to energy bin along the normal mixed waste bags and sorted at Gufunes. Up to 60% plastic waste diversion could expected with this method, which equals to about 10,000 tonnes of plastic content in MSW from 2012 (Table 7). Another way would be to emphasize the importance of plastic waste sorting to citizens and try to motivate them to bring their plastic packaging either to drop-off points or to the separate plastic waste collection containers around GRA. Setting a separate bin for only plastic would be risky but it would sort at least some of the plastic in MSW. Estimating the public acceptance of plastic separation would be another problem along the uncertainty of how often a standard sized bin for plastic should be emptied. It is possible that 4 separate bins could be too much for citizens to cope with but a gradual introduction to higher degree of household waste sorting might make the 4-bin system realistic in future. Either a 3-bin or 4-bin system could be experimented in a small area, e.g. in a single neighborhood to see what kind of feedback and results it would yield if direct application of the method to a whole municipality would be too much to ask for.

Metal content in MSW like empty food cans, wires, cables and wire coat hangers could be banned from household disposal. Magnet separation at Gufunes (SORPA 2013a) has been proven to work quite well but metal is still ending up to the landfill every day. In 2012 the landfilled metal quantity was a mere 3.2% (Table 7) but with the extent of waste quantity handled at SORPA, it equals close to 3.000 tonnes which is a tremendous amount of lost potential. Diverting about 40% from that amount would be already environmentally beneficial for the landfill.

Optical sorting of waste by bag color would seem to be a reliable waste sorting method but like any other method, it is not flawless (Williams 2005). It might be best to compromise if it would have to be set up only for one waste fraction, unlike in the previous alternative. Optical sensors might mistake other objects of the same color as colorful waste bags which they are meant to sort and it is also possible that sorted plastic bags might break during the collection or transportation to Gufunes plant, revoking the whole point of using a separate bag. As said in the previous chapter, hand-sorting of MSW is also one possibility, but it requires a lot of manual labor as the daily waste quantity passed through Gufunes plant is usually very large. Another method of sorting MSW could be a gravitational sieve which would sort either heavier objects from lighter ones or larger objects from small ones (Williams 2005). Depending on which waste fraction would be sorted, using a sieve might not be as effective as the other discussed sorting methods.

It is a positive fact that SORPA has used some of the shredded tires at Álfsnes for infrastructure and for covering the mound (SORPA 2013a). Rubber content in waste is generally very low, only less than one percent of total collected municipal waste (Table 7) and in separately collected waste streams it is even less (~0.1%, Table 3). If rubber would be separately collected, the simplest way to conduct the collection would be by setting one collection container to each drop-off point in GRA instead of disposing rubber to MSW. Another environmentally friendly action would be to increase P&P sorting from MSW. While it is unclear to me how much energy bin waste contains P&P after the ban of P&P disposal to energy bin, P&P waste is known to have a relatively high environmental impact in landfill based on its cellulose content (Pichtel 2014).

Landfilling inert waste is relatively cheap and poses a low risk to the environment in contrast to e.g. hazardous waste (Williams 2005). SORPA deposits a number of inert materials such as ash, construction waste, plaster and glass (Table 3) to a separate location at Àlfsnes (Figure 4) aside with what little inert waste comes along MSW bales (SORPA 2013a). Inert material can be assumed to be safe for continued landfilling since it mainly requires only the physical space at Álfsnes and it does not take up space from baled MSW which in turn has to be covered with soil materials (SORPA 2013a). If not already applied, ash brought to the landfill could be utilized for few purposes. If the collected ash is known to contain only a low amount of toxic substances such as heavy metals, it can be used as a road base material or as a part of waste covering material in the landfill (Pichtel 2014). SORPA collects and landfills annually rather large amounts of ash, as in 2012 it was 677 tonnes and 1468 tonnes in 2013 (Table 3).

Decreasing the moisture of biodegradable waste which cannot be used in the proposed biogas and fermenting plant would lower the odor generation, conserve space slightly and improve the overall quality of the landfill as well (Sasikumar & Krishna 2009). Any fairly dry and inactive available waste material could be also used to tie down the moisture in biodegradable waste, e.g. sawdust and ash from small to moderate amounts might be suitable if they do not contain high levels of contaminants. Dry waste is also easier to store, whether it is for temporary or permanent preservation.

Municipal households and small businesses should be able to sort some of their other waste fractions as well. Sorting glass, minerals, metal like food cans and clothes would be better to put somewhere else than to the energy bin. Delivering sorted waste to drop-off points would save some effort from SORPA and reduce the need of waste sorting hardware at Gufunes when MSW would have a higher fraction of plain unusable waste. Setting up smaller municipal collection points for sorted waste like metal and glass should motivate people towards recycling. It is possible that collecting sorted waste around GRA is not economically as feasible as collecting just energy bin and blue bin material (Moliis et al. 2012) but as waste collection is answering to the public demand, it would proactively serve the purpose of waste diversion.

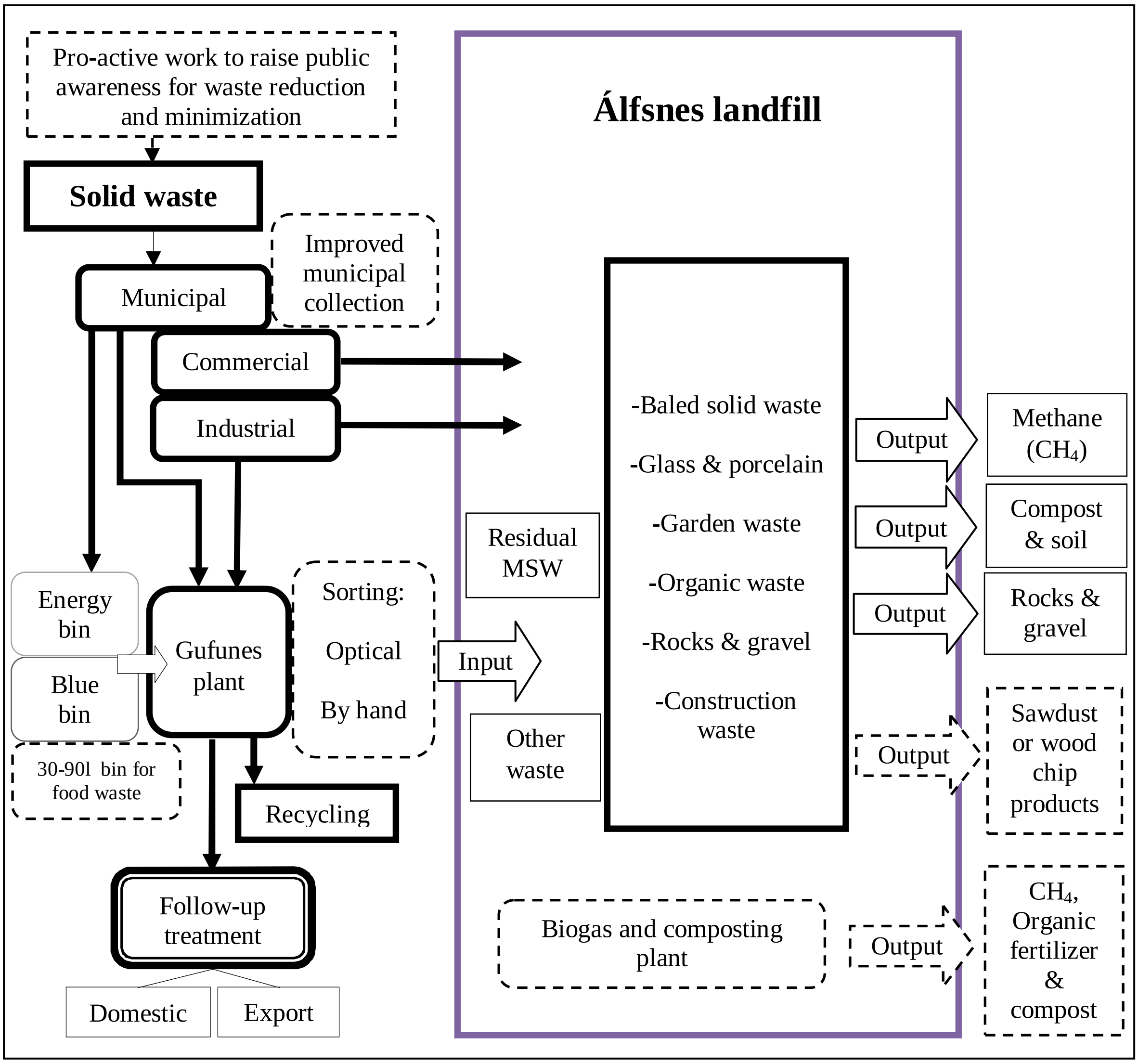


Figure 9. A summarized illustration of the proposed environmentally friendly alternative for landfilling of solid waste at Álfsnes with all inputs, outputs and supporting functions. Text boxes with cut-lines are the new proposed changes to the existing waste management system.

5.3.5 Balanced alternative

Some of the waste diversion suggestions from two previous alternatives are also adopted here. While this alternative (Figure 10) is not identical to any of the previous ones, improvements I suggest are meant to offer a realistic and convenient approach for waste diversion.

Home composting, metal, glass and mineral sorting in municipal households and small businesses are applicable in this alternative as well. If plastic does not have a separate bin or plastic bag to be disposed to energy bin waste, then it should be at least promoted for increased sorting rather than disposing it to energy bin. Delivering plastic waste to drop-off points and collection containers around GRA could settle upon about 20% plastic packaging diversion which would be already excellent amount to divert from Álfsnes. A moderate 10% of metal in MSW could be attempted to divert in the same manner as plastic. Biodegradable waste from municipal households should be sorted to a small insert which can be placed to the energy bin. Insert size could be around 20 to 30 liters so it would have to be emptied approximately 2 to 3 times a month and a bit more often during the warm summer months summing up to 24 to 36 times a year. 40% kitchen waste diversion could be expected from the combined home composting and sorting in households.

Biogas and fermenting plant proposed by SORPA (SORPA 2013a) is likely to be able to treat the majority of biodegradable waste delivered to Álfsnes. Additionally, small amounts of clean or dirty P&P can be used in the biogas plant as a filler in the process (White et al. 1995) and sawdust can be used in small or moderate quantities to fill in biomass for biogas and compost production as well (Ankidawa & Nwodo 2012). If the biogas plant will not be built anytime soon, decreasing the moisture in organic waste with pre-treatment and mixing dry material to it would possibly decrease the odor production and preserve some space for waste.

If sufficient dryness is achieved in collected MSW, a part of it could be used for refuse-derived fuel (RDF) or solid recovered fuel (SRF) production. This shredded waste can be co-combusted in small quantities along high-temperature combustion to enhance the burning process (Christensen 2010). The most optimal way to establish the use of refuse fuel would be by using an existing shredder for production of RDF or SRF but only if the demand for the material would be verified beforehand. Currently Gufunes plant is not capable of producing neither of the shredded fuels from solid waste and most likely at least moderate changes would have to be made in order to produce RDF or SRF. Usually a waste treatment plant is defined under a certain category like separators, plants for production of RDF or plants for treatment of organic material (Costi et al. 2004) but combining more of these functions can complicate the waste treatment and unnecessarily compromise the effectiveness (Costi et al. 2004). As was covered in the previous chapter, waste sorting by hand, gravitational sieve and optical sorting could all be utilized if certain waste would need to be sorted but either optical sorting or any other preferred method by SORPA is suitable in this alternative. As I have proposed to sort some of the biodegradable waste and plastic in municipal households, using optical sorting system would save the citizens and businesses from the trouble of investing to new waste containers while still achieving some level of success in waste diversion. If there is only one waste fraction sorted and put to energy bin, like kitchen waste in a colorful plastic bag, the optical sorting could be compromised with some more convenient solution. Hand-sorting is most likely out the question since the daily waste volume at Gufunes plant is so high that sorting all arriving MSW even inaccurately would take a tremendous amount of labor to be performed efficiently. However, if a potential technology would be available, hand-sorting of waste would collaborate well together with the improved household waste sorting.

In addition to the treatments I have suggested in the previous alternatives, some of the waste fractions in separated streams could be utilized and diverted from the landfill. In the midst of fire wood scarcity in Iceland (Thórhallsdóttir 2007), received darken wood chips at Àlfsnes could be considered to be utilized for commercial purposes. Unpolluted wood chips can be used in small industrial burners, fireplaces and municipal ovens for heat production. There is no doubt that the extent of applications for wood chips is not vast but the demand for such material could be examined further. Even a small waste diversion is significant when thinking about the overall benefit.

Another interesting waste fraction is disposable diapers. Found in collected MSW, in 2012 the amount of diapers was 6.6% or approximately 6000 tonnes (Table 7) which is enough to make a notable difference if it is diverted from the landfill. Disposed diapers are mostly consisted of organic matter but they also have superabsorbent polymers (SAP) and cellulose pulp in them. SAP is the key difficulty in diaper recycling as it can be very persistent in a composting process. Compost produced with about 3% of disposable diapers have presented a slightly higher level of zinc which can prevent the usage of large amounts of diapers in composting process (Colón et al. 2010). The quantity is still so high in MSW that in my opinion it would be reasonable to study diaper utilization further.

Using a multi-compartment waste collection container on a trailer platform in the near vicinity of major supermarkets could motivate citizens to take their sorted household waste along the same trip to run errands or buy groceries. Additionally, SORPA should renew their waste sorting instructions for municipal households in order to improve both the waste sorting and waste prevention. Waste fractions like kitchen waste and P&P in MSW are partially produced because of the inefficient use of raw materials (Cheremisinoff 2003). While the preferences in use of waste producing material is out of the reach of SORPA, waste prevention and minimization can be promoted e.g. by making a new recycling pamphlet for municipal households and businesses to divert more waste.

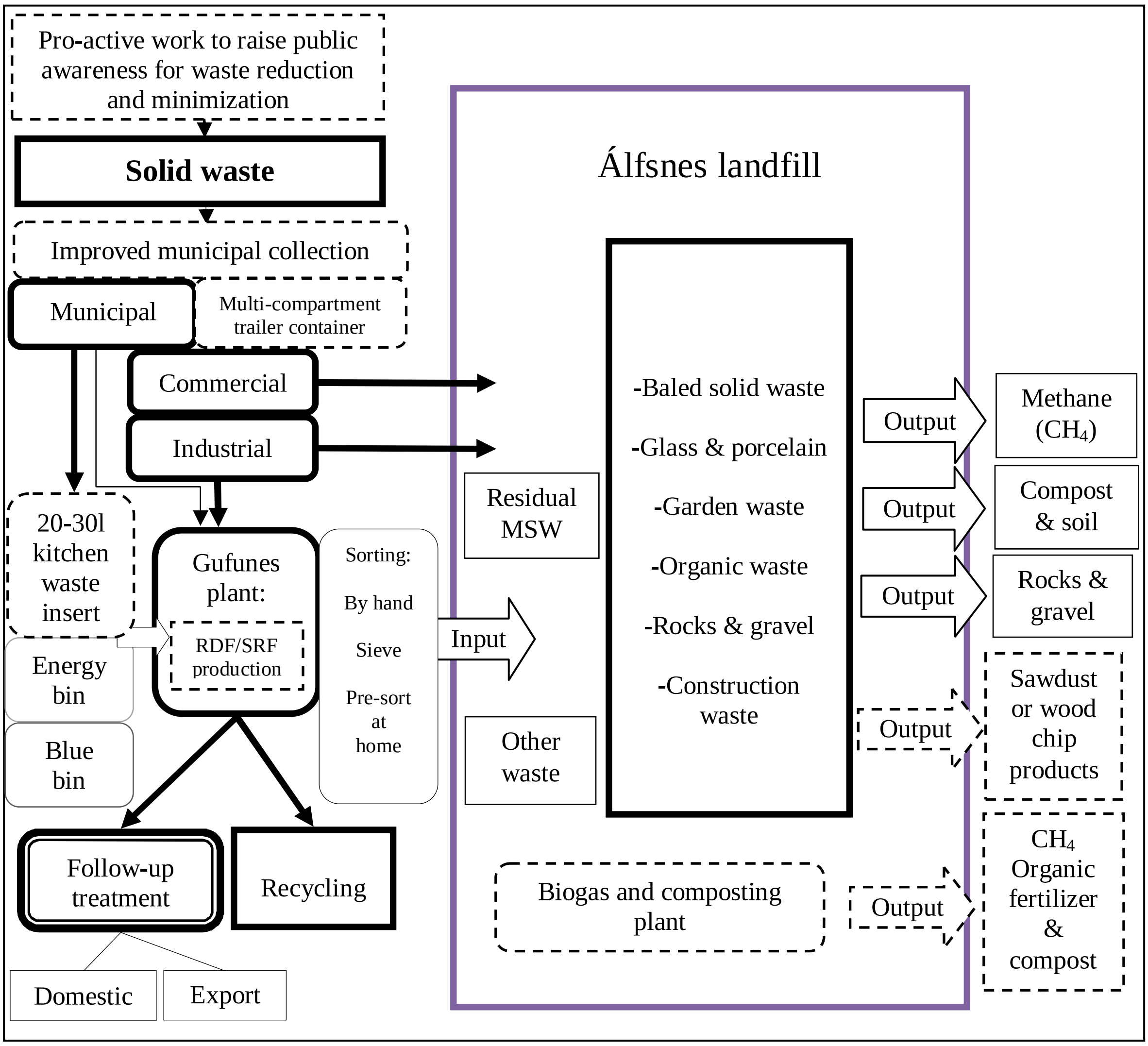


Figure 10. A summarized illustration of the proposed balanced alternative for landfilling of solid waste at Álfsnes with all inputs, outputs and supporting functions. Text boxes with cut-lines are the new proposed changes to the existing waste management system.

Table 8. The summary of proposed waste diversion methods to improve the current waste management of SORPA. Small “x” is the suggestion made in an alternative and “-“ is an improvement not covered in an alternative of chapters 5.3.2. – 5.3.5.

	1. Current setup	2. Cost-effective alternative	3. Environmentally friendly alternative	4. Balanced alternative
Biogas plant	x	x	x	x
MSW iversion rate (%) from MSW:				
Plastic packaging	-	40	60	20
Kitchen waste	-	40	60	40
Metal waste	-	20	40	10
Waste sorting:				
By hand or manually	-	x	-	x
Optical (e.g. NIR)	-	x	x	-
Gravitational sieve	-	-	x	x
Household sorting	-	x	x	x
Separate bin or insert for households	-	-	x	x
Better regional collection or sorting	-	x	x	x
Any preferred sorting method	x	-	-	x
Diversion from separate streams				
Ash	-	x	x	-
Sawdust	-	x	x	x
Wood chips	-	x	x	x
RDF or SRF production	-	-	-	x
Diapers	-	-	-	x
Other waste diversion means:				
New waste sorting instructions	x	x	x	x
Environmental education	x	x	-	-
Waste minimization	x	-	-	x
Waste prevention	x	-	-	x
Home composting	x	x	x	x

6 DISCUSSION

The variation of influential factors in waste management states that no single waste sorting solution has the capacity to suit the needs of every waste management scenario (Ordoñez et al. 2014). For that reason I came up with a decision to evaluate three different alternatives for the current waste management of SORPA to improve waste diversion from Álfsnes landfill. Using simple trade-offs between economical and environmental objectives are often difficult and result into using multi-objective framework to achieve the goals (Robba et al. 2008), but despite the labels of the alternatives I chose: cost-effective (2), environmentally friendly (3) and balanced (4) alternative, they all are more or less combining both the environmental and cost-effective aspects. Only the emphasis is different.

Using more than one and exactly the chosen three new alternatives for future consideration was a good choice in my opinion as it gives more perspective to the planning but it does not exten the thesis too far to take the focus away from the initial waste diversion and waste management improvement. While one alternative might portray the planned situation too one-sidedly, too many alternatives have a risk of giving too much similar options between alternatives and obscuring the end result. Keeping the planning generally straightforward and simple ensures that the set goals are met. To meet the goals set in this thesis, I have worked to my best ability to provide realistic and applicable alternatives for SORPA to choose from closest to the company's preference. It will be up to SORPA whether or not they deem my suggestions applicable. If they want to combine the results or use only a part of an alternative, it should be fine as long it takes the waste diversion matter further and improves the landfill quality from the current situation.

To make an alternative for waste management so functional that it actually improves the current system, options between the alternatives are going to be generally similar as my analysis has shown. Available data from SORPA helped greatly to narrow down the applicable options for the alternatives and based on the data, I made e.g. the decision of not proposing waste incineration to any of the new alternatives. The distinction between the assessed alternatives had to be made somehow visible while still keeping each alternative realistic and considerable for utilization. When very unlikely options like founding a new landfill or building a completely new waste sorting facility were ruled out from the planning, the assessment was then easier to carry on. In the end, I managed to distinguish each of the new alternatives to match their description (Table 8) as it can be seen that alternatives possess some unique propositions which others do not have. Many of the suggested improvements are same in all alternatives like household waste sorting and utilization of some of the separate waste streams. These improvements are often solely bound neither by economical or environmental factors (Sasikumar & Krishna 2009). That is why the major differences in the new alternatives are brought about the intensity of waste diversion and proposed investments.

The question to solve was to ambitiously answer what are the economical and environmental impacts of diverting waste streams from the landfill in the Icelandic context. As no solid financial or environmental data was available for the thesis, all decisions made were based on estimations, literature on the subject and the waste data provided by SORPA. If the suggestions made in this thesis will take effect later on, economical impact of waste diversion can be calculated when waste diversion has taken effect for a long enough period to track the changes in treated and landfilled waste quantities. For reference, usual monitoring period for waste diversion is one year as seasonal changes may occur (Sasikumar & Krishna 2009). No estimation made for waste diversion is ever foolproof and only time can show what the net economical benefit of waste diversion from Álfsnes will be. Waste management and landfilling of solid waste often possess a higher degree of ethical values such as if landfilling is a good thing to do in the first place. That kind of issues cannot simply be measured by economical counters. However, it is safe to say that if treating less unusable waste and sorting more waste that is worth money such as plastic and P&P, waste diversion will be economically beneficial at least in minor scale.

Measuring the environmental impact of waste diversion without any solid environmental data was only based on literature and personal evaluation, but considering the assessed measures for waste diversion in the proposed alternatives, environment can only benefit when waste is directed more and more to recycling and re-use, returning it to circulation as new raw material rather than leaving it to pose a potential threat to surrounding environment. Especially diverting organic waste from landfill is known to decrease greenhouse gas emissions (Liamsanguan & Gheewala 2007), thus reducing the net environmental impact. Diverting more durable waste like metals and plastic decrease the environmental further since the disintegration of this kind of waste is extremely slow or non-existent in a mound (Williams 2005). Thereby the environmental impact of waste diversion from Álfsnes is considered to be positive at least in minor scale as all of the proposed alternatives are directing waste more or less away from the studied landfill. With this information, I have come to a conclusion that the question of the study has been answered to the extent is it possible with the current information available.

The main goal of this thesis was to find improved alternatives for waste management compared to the current solid waste disposal in Álfsnes landfill of SORPA by means of waste diversion. As can be seen from the Results –chapter, I have produced three new alternatives which have a number of potential proposed additions to compare with the current system of SORPA. Not having a sufficient knowledge or having heavy personal preferences can distort the decisions and it is possible that some applicable waste treatment or diversion method has been left uncovered by accident in this thesis, but I am certain that the suggested improvements are fully functional and sufficient as they are currently presented. Main objective of this thesis was to help SORPA reduce the environmental and economical costs of landfilling and improve the waste management system in GRA in the long scale. This cannot be answered simply by relying on results acquired in the work, but if SORPA will adopt any part of this thesis to its waste management system, the thesis has fulfilled its purpose. I went well in depth to research a lot of material to get acquainted on the subject and to be able to give an inclusive and well-reasoned answer to all of the dilemmas in the thesis.

As for the individual waste diversion propositions in the new alternatives, the proposed biogas and fermenting plant is one of the decisive features of SORPA’s future as it works towards the goal of European Union in banning the landfilling of organic waste by 2020 (1999/31/EC). There is a lot of uncertainty in waste diversion practices such as unforeseeable effectiveness of individual diversion methods (Sasikumar & Krishna 2009) and the difficulty of estimating how well the public will answer to the demands set by the local or regional waste operator. Waste reduction and diversion has been driven forward in some European countries like UK and Italy by increasing the landfill tax (Nicolli & Mazzanti 2013), but as the landfill tax system is not applied in Iceland (SORPA 2013a), more straightforward actions are required to improve waste diversion.

Icelandic waste management is still relatively young, originating to the beginning of 1970’s (UST 2006). Main waste management functions are already viable and working well in the capital region (SORPA 2013a) and obstacles like coping with the prevalent weather conditions have been already overcome. Remaining problems like incapability in domestic treatment of waste fractions such as P&P and plastic are still on the way to support the current waste management, but the situation is also forecasting a possible business activity to near future in Iceland. It is certain that some solutions like poor waste sorting can make waste management cheaper, but it would compromise the sustainability of the activities by adding more volume to already burdened landfill, complicating the situation further and making waste diversion even more essential than before.

Waste management planning is always case specific (Pichtel 2014) and after the conclusion of assessing the new improved alternatives, it is possible that this thesis might not offer much new information to the field but it is answering to the demand in Icelandic context for sure because all the decisions were based on the real-life data received from SORPA. It is likely that SORPA has already looked into some of the suggestions I have proposed here but I also hope to offer something new for SORPA to consider. The emphasis in waste diversion was set to MSW, SORPA's proposed biogas plant and to the importance of sorting and recycling solid waste. MSW was chosen for closer inspection due to its annual quantity and well-known characteristics (SORPA 2013a). The political emphasis on municipal waste is very high because of its complex character due to its composition, its distribution among many waste generators and its link to consumption patterns (Williams 2005).

On the other hand, recycling as a waste diversion method is an activity that has a lot of potential to make citizens contribute to the mutual goal as well. Recycling is not a goal in and of itself, but rather a necessary response to societal consumption patterns. Increasing the amount of discarded material recovered through recycling is a task of considerable importance in order to divert waste from and extend the lifetime of existing landfills (Mueller 2013). Waste reduction and prevention happening before an item becomes waste is what takes place in households, industry or other places which are using goods that generate waste (Zorpas & Lasaridi 2013). GRA has also already an existing base of locations collecting for example plastic bottles, old clothes and metal food cans (SORPA 2013a) but despite the available services, the waste collection data suggests (Annex 1) in all likelihood that said waste is still finding its way to MSW (SORPA 2013a). Waste reduction, prevention and minimization are important measures to address but they are partially out of the reach of SORPA and also out of the scope of this thesis. As a last link in the waste management chain, SORPA can still make an active effort to change attitudes towards recycling-inducing activities such as methods mentioned above. Public is often willing to contribute even without any trade-offs (Czajkowski et al. 2014).

Initiating new waste diversion methods in GRA will take time to get fully functional and it takes even longer to start getting positive results, but the bottom line is that if less waste ends up to disposal in municipal households, businesses and industry, logically less waste would have to be transported for final disposal at Álfsnes. Resulting savings could be then directed to other activities like possible new investments. Further inclusion of possible new waste management regions to SORPA’s jurisdiction is likely to increase the demand for landfilling and waste collection, thus complicating the system more by adding to already burdened transportation distances and treatment capacity and making the changes even more necessary than before in addition to waste increase along the population growth. What comes to the actual implementation for the future waste management of SORPA in GRA, there is many variants that all have to be taken into account to ensure and eventually surpass the quality of the current waste management system.

7 CONCLUSIONS

7.1 Waste diversion in Greater Reykjavík area

Even as far as this thesis has gone in depth to examine Álfsnes to improve the current waste management and augmented waste diversion, it is still only a scratch to the surface in a pursuit of getting closer to something like a zero-waste strategy. This thesis proposes a set of potential ways to improve the current system of SORPA to divert solid waste from Álfsnes in future and the majority of proposed methods have been confirmed in literature to be practical and usable, but in the end the initiative to use them has to be taken by a higher authority. Whatever solution SORPA will end up using in order to divert solid waste in future, changes will be necessary to decrease the burden on the landfill.

If the motivation for waste diversion is not found in economical benefits, then it should be in environmental and ethical values and in the responsibility of everyone to make the world a bit better place to live tomorrow towards a sustainable society. All essential values were manifested during the planning of the alternatives proposed in this thesis. While some of the proposed methods are more applicable than others and some means such as waste reduction is out of SORPA’s direct control, I have written and given suggestions in the limits of this thesis to my best own knowledge and believe that every alternative is equally possible to implement. Making even simpler decisions in planning could have increased the applicability of the alternatives, but since this thesis was searching a proactive solution to divert waste from Álfsnes, it was outright reasonable to expand the content.

Follow-up question for this thesis would be how to get citizens to voluntarily sort their waste more efficiently. Building for example multi-compartment collection platforms to use around the capital area is not difficult or too expensive and increased waste collection cycle would be a sole reality as well but as long as there is no one to fill the containers, they are not serving their purpose. In all likelihood a successful diversion can be observed in less than a year but a full year should be sufficient interval for a reliable comparison with the previous waste collection and landfilling data. Further on, what can be done is to improve the waste sorting, apply waste management techniques recognized elsewhere in the world and examine connections between waste generation and disposal points to improve waste diversion in national level.

7.2 Applicability of ARVI tool

ARVI analysis tool has proven to be functional and flexible in this thesis for analyzing environmental statistics data. It is also suitable for environmental planning which covers more than one type of variant. Strong features in ARVI are that it requires adequate background information to ensure reliable results in return of all the effort put into it and its interface is very clear even for an inexperienced user. Setting up the impacts for studied alternatives was challenging and took a while to carry out, but I came up with a satisfactory solution to carry the analysis further. The amount of detail in ARVI is rather high but I understand that it is made to guarantee a successful analysis. Based on ARVI analysis conclusion and my own estimation, the most viable alternative is the balanced alternative as its approach is subtly the closest to the current landfilling setup of all three. ARVI analysis gave good reference and framework to which impacts I should concentrate on as I had to make all the impacts fit the proposed alternatives to get a comprehensive result from the analysis.

On the downside of ARVI, from my inexperienced point of view it was difficult to anticipate the sufficiency of my data and how it would fit the analysis without ending up to kind of a “back and forth” thinking where I would need to rethink whether or not an impact chosen for evaluation fits the data. ARVI can also turn out to be rather problematic if for example you try to make a distinction between an impact significance chart with either -1 (low negative) or -2 (moderate negative)–value for every impact, when only the outlook of the analysis changes, keeping the nominal differences between alternatives exactly the same. From ARVI analysis results, the impact significance chart was the most applicable feature in this work as it supported the completion of the final analysis. In the end, ARVI succeeded in providing the kind of an analysis I expected to have and it supported the further analysis together with other available data resulting into a successful thesis.

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Annex 1. 29 waste fractions from MSW examined in Gufunes household waste study 1.0 in November 2012 and their respective weights (SORPA 2013c).

Waste examination: 12.11.12					
Nr.	Category of waste	Gross weight *kg	Container weight *kg	Net weight*kg	% of gross weight
1	Corrugated paper	7	4	3	42.9
2	Thick paper	14.255	4.89	9.365	65.7
3	Paper	14.120	5.36	8.76	62.1
4	Plastic film - colorless/ Not printed	11.260	9.73	1.53	13.6
5	Plastic film - dyed/ printed	19.825	11.37	8.455	42.7
6	Plastic containers (other than film)	12.665	5.68	6.985	55.2
7	Styrofoam	2.560	1.72	0.84	32.9
8	Other plastic	1.870	0.64	1.23	65.8
9	Deposit containers - plastic	1.705	1.29	0.415	24.4
10	Deposit containers - glass	1.725	0.75	0.975	56.6
11	Deposit containers - metal	2.180	2.03	0.15	6.9
12	Clothes / garment / textiles	3.260	1.94	1.32	40.5
13	Candle residue	2.000	1.50	0.5	25
14	Metals - magnetic	3.500	1.50	2	57.2
15	Metals - non-magnetic	2.500	2.00	0.5	20
16	Minerals	4.965	0.48	4.485	90.4
17	Timber - untreated	0.005		0.005	100
18	Timber - treated	2.060	1.62	0.44	21.4
19	Organic kitchen waste	50.050	9.19	40.86	81.7
20	Garden waste	2.245	1.90	0.345	15.4
21	Cosmetics	0.840	0.49	0.35	41.7
22	Drugs	0.850	0.30	0.55	64.8
23	Bulbs	0.005		0.005	100
24	Batteries	0.130	0.08	0.05	38.5
25	Electronics	0.105		0.105	100
26	Hazardous	0.330	0.29	0.04	12.2
27	Diapers	6.000	1.50	4.5	75
28	Rubber	0.210		0.21	100
29	Dust, ash and sweepings	2.585	2.00	0.585	22.7
	Total	170.805	72.195	98.61	57.8

Annex 2. ARVI impact assessment sheet for the current setup (ARVI 2014).

Current setup

Impact	Characteristics of sensitivity			SENSITIVITY	Characteristics of magnitude			MAGNITUDE	SIGNIFICANCE
	Existing regulations and guidance	Societal value	Vulnerability for changes		Intensity and direction	Spatial extent	Duration		
1.1 Environmental stress	Mod.	Mod.	Low	Mod.	Mod. -	Mod.	High	Low +	Low +
1.2 Climate and air quality	Mod.	Mod.	Low	Mod.	Low -	High	High	Low +	Mod. +
1.3 Water systems	Mod.	Mod.	Mod.	Mod.	Low -	Mod.	High	Low +	Mod. +
2.1 Affordability	Low	Mod.	Low	Low	Low -	Mod.	No impact	Low +	Low -
2.2 Applicability and technical potency	Low	Low	Low	Low	No impact	Low	No impact	No impact	Low +
2.3 Maintainability	High	Mod.	Low	Mod.	Low +	Mod.	Low	Low +	Low +
2.4 Waste availability	Low	Low	Mod.	Low	No impact	Mod.	Low	Low +	Low +
2.5 Public acceptance	Mod.	High	Mod.	Mod.	Low +	Mod.	Low	Low +	Low +
2.6 Level of change required	Low	Low	Low	Low	No impact	No impact	No impact	No impact	No impact
2.7 Landfill outputs	Low	Low	Low	Low	Low +	Low	No impact	Low +	Low +
2.8 Living conditions	Mod.	Mod.	Low	Mod.	Low +	Mod.	Low	Low +	Low +
2.9 Traffic	Low	Mod.	Mod.	Mod.	No impact	Low	Low	Low +	Low -
2.10 Employment	Low	Mod.	Low	Low	Low +	Mod.	Low	Low +	Low +
2.11 Land use	Mod.	Low	Low	Low	Low -	Low	Mod.	Low -	Low -
2.12 Landscape	Mod.	Mod.	Mod.	Mod.	Low -	Low	Mod.	Low -	Low -

Annex 3. ARVI impact assessment sheet for the cost-effective alternative (ARVI 2014).

Cost-effective alternative									
	Characteristics of sensitivity				Characteristics of magnitude				
Impact	Existing regulations and guidance	Societal value	Vulnerability for changes	SENSITIVITY	Intensity and direction	Spatial extent	Duration	MAGNITUDE	SIGNIFICANCE
1.1 Environmental stress	Low	Low	Mod.	Low	Mod. -	Mod.	High	Low +	Mod. +
1.2 Climate and air quality	Mod.	Mod.	Low	Mod.	Low -	High	High	Mod. +	Low -
1.3 Water systems	Mod.	Mod.	Mod.	Mod.	Low -	Mod.	High	Mod. +	Low -
2.1 Affordability	Mod.	Very high	High	High	Low +	Mod.	Mod.	Mod. +	High +
2.2 Applicability and technical potency	Mod.	Low	Mod.	Mod.	Mod. -	Low	Mod.	Low +	Low -
2.3 Maintainability	Mod.	Low	Mod.	Mod.	Low +	Low	Low	Low +	Mod. +
2.4 Waste availability	Low	Mod.	Mod.	Mod.	Low -	Mod.	Mod.	Mod. +	Low -
2.5 Public acceptance	Mod.	Low	Mod.	Mod.	Mod. +	Mod.	Mod.	Mod. +	Low -
2.6 Level of change required	Low	Mod.	Mod.	Mod.	Mod. +	Mod.	Mod.	Mod. +	Mod. +
2.7 Landfill outputs	Low	Low	Low	Low	Low +	Low	Low	Low +	Mod. +
2.8 Living conditions	Mod.	Low	Low	Low	Low -	Mod.	Low	Low +	Low -
2.9 Traffic	Low	High	Mod.	Mod.	Low +	Mod.	Low	Low +	Low +
2.10 Employment	Low	Low	Mod.	Low	Low -	Mod.	Mod.	Low +	Mod. +
2.11 Land use	Mod.	Low	Mod.	Mod.	Low -	Low	Mod.	Low -	Low +
2.12 Landscape	Mod.	Low	Low	Low	Low -	Low	Low	Low -	Low -

Annex 4. ARVI impact assessment sheet for the environmentally friendly alternative (ARVI 2014).

Environmentally friendly alternative									
	Characteristics of sensitivity				Characteristics of magnitude				
Impact	Existing regulations and guidance	Societal value	Vulnerability for changes	SENSITIVITY	Intensity and direction	Spatial extent	Duration	MAGNITUDE	SIGNIFICANCE
1.1 Environmental stress	Mod.	High	High	High	Low -	High	High	High +	High +
1.2 Climate and air quality	Mod.	Mod.	Low	Mod.	Low -	High	High	High +	High +
1.3 Water systems	Mod.	Mod.	Mod.	Mod.	Low -	Mod.	High	Mod. +	High +
2.1 Affordability	Mod.	Low	Mod.	Mod.	Low -	Mod.	Low	Low +	Low -
2.2 Applicability and technical potency	Mod.	Low	Low	Low	Mod. -	Mod.	Mod.	Low -	Mod. -
2.3 Maintainability	Mod.	High	Mod.	High	Low +	Low	Low	Low +	Low -
2.4 Waste availability	Low	High	Mod.	Mod.	Low -	Mod.	Mod.	Low +	Low +
2.5 Public acceptance	Mod.	High	Mod.	Mod.	Mod. +	High	High	High +	Low +
2.6 Level of change required	Low	Mod.	Mod.	Mod.	Mod. +	High	High	High +	Low -
2.7 Landfill outputs	Low	Mod.	Low	Low	Mod. +	Low	Mod.	Mod. +	High +
2.8 Living conditions	Mod.	High	Low	Low	Low +	Mod.	Low	Low +	High +
2.9 Traffic	Low	High	Low	Mod.	Low -	Mod.	Low	Low +	Mod. +
2.10 Employment	Low	Mod.	Low	Low	Mod. +	Mod.	Mod.	Mod. +	Low -
2.11 Land use	Mod.	Mod.	Low	Mod.	Mod. +	Low	Mod.	Mod. +	Mod. +
2.12 Landscape	Mod.	Mod.	Mod.	Mod.	Mod. +	Mod.	Mod.	Mod. +	Mod. +

Annex 5. ARVI impact assessment sheet for the balanced alternative (ARVI 2014).

Balanced alternative	Characteristics of sensitivity				Characteristics of magnitude				
Impact	Existing regulations and guidance	Societal value	Vulnerability for changes	SENSITIVITY	Intensity and direction	Spatial extent	Duration	MAGNITUDE	SIGNIFICANCE
1.1 Environmental stress	Mod.	Mod.	Mod.	Mod.	Low -	Mod.	High	Mod. +	Mod. +
1.2 Climate and air quality	Mod.	Mod.	Low	Low	Low -	High	High	Mod. +	Mod. +
1.3 Water systems	Mod.	Mod.	Mod.	Mod.	Low -	Mod.	High	Mod. +	Mod. +
2.1 Affordability	Mod.	Mod.	High	High	Low -	Low	Low	Low -	Mod. +
2.2 Applicability and technical potency	Mod.	Low	Mod.	Mod.	Low -	Mod.	Low	Low -	Low -
2.3 Maintainability	Mod.	Mod.	Low	Low	Low +	Low	Low	Low +	Mod. +
2.4 Waste availability	Low	Mod.	Mod.	Mod.	Low -	Mod.	Low	Low +	Low +
2.5 Public acceptance	Mod.	Mod.	Mod.	Mod.	Low +	Mod.	Mod.	Mod. +	Low -
2.6 Level of change required	Low	Mod.	Mod.	Mod.	Mod. +	Mod.	Mod.	Mod. +	Low +
2.7 Landfill outputs	Low	Mod.	Low	Low	Low +	Low	Mod.	Low +	Mod. +
2.8 Living conditions	Mod.	Mod.	Low	Mod.	Low +	Mod.	Low	Low +	Mod. +
2.9 Traffic	Low	High	Mod.	Mod.	Low -	Mod.	Mod.	Low +	Low +
2.10 Employment	Low	Mod.	Low	Low	Low +	Mod.	Low	Low +	Low +
2.11 Land use	Low	Mod.	Low	Low	Low +	Low	Mod.	Low +	Low +
2.12 Landscape	Mod.	Mod.	Low	Mod.	Low +	Low	Mod.	Low +	Low +

Current setup			
Impact	Sensitivity	Magnitude	Significance
1.1 Environmental stress	The state of current landfilling of solid waste in Álfsnes. No measured stress to surrounding environment but in all likelyhood traceable emissions from the landfill to environment are present.	Water systems around and in the landfill, air quality and animals or plants in and around the landfill are not actively monitored except for odors generated in the landfill. Excessive measures are only taken if a problem arises.	The landfill should not pose any threat to the environment. Improved waste management contributes to conservation but additional actions to measure or control impacts to nature are not taken.
1.2 Climate and air quality	Climate is affected mostly by greenhouse gas emissions from the landfill. Part of the methane (CH4) generated in the landfill mound is collected for commercial use.	Odors rising from the landfill affect the immediate vicinity of the landfill, and greenhouse gas emissions are prone to having a much more widespread influence in climate.	Impact on climate and air quality is especially important to surrounding living areas but on a wider scale less emissions to atmosphere contribute to the prevention of climate
1.3 Water systems	Ground water and sea next to the landfill are at least theoretically vulnerable to pollution by leachate leakage or water run-off from the waste mound.	Landfill affects the water resources in its immediate proximity.	Leachate and contaminated water run-off from the landfill to surrounding water systems should be prevented at all costs.
2.1 Affordability	Financial input needed for the system to make it functional. New investments make the alternative less affordable. Currently no major investments needed except for the biogas plant. Low sensitivity.	Financial input is not only needed at the landfill but also to fit the other facilities of SORPA for a desired waste management alternative.	Not significant for current situation.
2.2 Applicability and technical potency	Current technology and waste treatment methods are suitable and no changes are to be expected.	Concerns only the landfill.	Significance rises when larger and more complicated applications are planned for the landfill.
2.3 Maintainability	Álfsnes landfill is maintainable as proven by recent years without any drastic changes in the landfill structure. Higher degree of changes to the landfill or SORPA's waste management system are likely to influence the functionality.	Concerns only the landfill.	The waste management system has to be designed so that it remains functional and operational for longer periods.
2.4 Waste availability	Currently solid waste is available at all times and for all the functions of the landfill in Álfsnes. Low sensitivity.	Concerns the landfill, arriving waste from Gufunes and collection network.	Minor significance for the current situation.
2.5 Public acceptance	The reception of changes to waste management in public depends on the magnitude of changes and how much input from public is required to make the system functional.	Extends to the municipal households and small businesses which would be influenced if e.g. stricter waste separation rules would be implemented.	Minor significance in current situation.
2.6 Level of change required	Current system does not need to change to function properly.	Extends at most to the municipal households, Gufunes plant and Álfsnes landfill.	No impact in this alternative.
2.7 Landfill outputs	Possible outputs produced at the landfil. Currently compost, metan gas (CH4) and gravel.	Concerns only the landfill.	Larger amount of landfill outputs is a surplus especially when it is profitable but output production should not compromise waste diversion from the landfill.
2.8 Living conditions	Neighboring residential areas of Álfsnes landfill have suffered from occasional bad odors coming from the landfill. Increased solid waste landfilling is likely to increase unwanted odor emissions if the waste is not pre-treated or covered properly.	Extends to the surroundings of the landfill, no further than 5-10 kilometres.	It is important to take to an account how the surrounding environment is influenced by the landfill. Every citizen has a right to clean air and water, no matter where they live.
2.9 Traffic	Traffic into, in and out of the landfill is currently moderate. Increased waste quantity is likely to increase traffic.	Concerns only the landfill.	Minor significance in current situation.
2.10 Employment	Concerns not only the landfill but also the other facilities of SORPA. Currently the waste management scheme is estimated to grow, so the employment is steady.	Concerns the landfill and other facilities of SORPA as waste diversion and its effectiveness is partially dependant of competent employees who actively contribute to manual labor.	Significant as a company cannot run itself without a sufficient amount of competent employees. Reducing employees is also likely to act as a demotivating factor to remaining employees.
2.11 Land use	Increased landfilling of solid waste would increase the land use, whereas decreased waste amount would conserve the space for a longer period. Due to overfilling of the landfill, usable space is currently sufficient.	Collected solid waste volume is directly related how much of MSW is landfilled in the end. Only the land area used for landfilling is considered.	Landfill has a maximum filling capacity and it should not be exceeded.
2.12 Landscape	Increased landfilling of solid waste would increase the changes in landscape. It is important to modify the landfill so that it does not pose an environmental threat.	Concerns only the landfill.	Esthetical outlook of the landfill as well as not posing an environmental threat to landfill and its surroundings are both important features.

Annex 6. ARVI impact reasoning sheet for current waste management setup of Àlfsnes (ARVI 2014).

Cost-effective alternative			
Impact	Sensitivity	Magnitude	Significance
1.1 Environmental stress	No measured stress to surrounding environment. Efforts to decrease stress from current levels is not intentionally conducted by financial means not neither should stress be increased. Estimated low sensitivity.	Water systems around and in the landfill, air quality and animals or plants in and around the landfill are not actively monitored except for odors generated in the landfill. Excessive measures are only taken if a problem arises.	The landfill should not pose environmental or socio-economical stress to its surroundings.
1.2 Climate and air quality	Climate is affected mostly by greenhouse gas emissions from the landfill. Increased organic waste landfilling is not expected as it would contribute to increased emissions.	Odors rising from the landfill affect the immediate vicinity of the landfill, and greenhouse gas emissions are prone to having a much more widespread influence in climate.	Impact on climate and air quality is especially important to surrounding living areas but on a wider scale less emissions to atmosphere contribute to the prevention of climate
1.3 Water systems	Ground water and sea next to the landfill are at least theoretically vulnerable to pollution by leachate leakage or water run-off from the landfill. Moderate sensitivity.	Landfill affects the water resources in its immediate proximity.	Leachate and contaminated water run-off from the landfill to surrounding water systems should be prevented at all costs.
2.1 Affordability	Only reasonable investments are considered for this alternative to remain competitive against others.	Financial input is not only needed at the landfill but also to fit the other facilities of SORPA for a desired waste management alternative.	High significance.
2.2 Applicability and technical potency	Minor technological changes are likely to be needed but with expenses in control. Moderate sensitivity, depending on the magnitude of expected waste diversion.	Concerns only the landfill.	Significance rises when larger and more complicated applications are planned for the landfill.
2.3 Maintainability	Estimated to be as maintainable as the current landfill setup. Moderate sensitivity.	Concerns only the landfill.	The waste management system has to be designed so that it remains functional for longer periods, especially if cost-effectiveness is desired.
2.4 Waste availability	Solid waste is estimated to be available for all the necessary waste treatments.	Concerns the landfill, arriving waste from Gufunes and collection network.	Minor significance, constant waste streams are needed to keep the system profitable and competitive against other options.
2.5 Public acceptance	The reception of the new waste management principles in public depends on the magnitude of changes and what kind of input is required from public. Moderate sensitivity.	Extends to the municipal households and small businesses which would be influenced if e.g. stricter waste separation rules would be implemented.	Minor significance.
2.6 Level of change required	Changes are required to improve the system towards an cost-effective approach but the functionality of the landfill will not be compromised. Moderately vulnerable to changes, low sensitivity.	Certain financial investments would have to be made to implement the cost-effective alternative, e.g. collection vehicles with multiple collection compartments and/or optical sensors to automatize the waste separation before landfilling.	Significance rises depending on how cost-effective system is desired. Significance remains lower by minimizing additional investments and increasing the consumer role in waste management.
2.7 Landfill outputs	Along the landfill functions, outputs are expected to remain at least the same as they are in the current landfill set-up. No fluctuations in output quantity are expected.	Concerns only the landfill.	Moderate significance, increased amount of outputs is expected to result into more income and savings but output production should not compromise waste diversion from the landfill.
2.8 Living conditions	Landfilling of organic waste is estimated to contribute the most to the quality of living conditions close to the landfill. Low sensitivity if the waste management will remain at least as it is currently.	Extends to the surroundings of the landfill, no further than 5-10 kilometres.	Minor significance, no impact to surrounding areas is desired.
2.9 Traffic	Traffic to, in and out of the landfill is dependant of various factors such as the future waste quantity and the amount of waste collection vehicles. Decreased traffic is estimated be optimal to run down the transportation costs.	More unified and scheduled waste transportation would result into less expenses but also likely to more stress on smaller amount of vehicles which would be actively circulated.	Moderate significance.
2.10 Employment	The exact demand for employment can only be defined after the waste diversion would take place in Álfsnes. Waste diversion does not only affect the landfill but also the waste collection network around it.	The cost-effective alternative would require the labor force to be re-evaluated as automatization and re-scheduling waste delivery can save workload significantly. Some vacancies could be given up to save more in expenses.	Moderately significant, savings can be made by re-evaluating the demand for employment but reduction is not recommended to maintain the system functionality.
2.11 Land use	Waste diversion success defines the saved or opened space for waste. When less waste is delivered to the landfill, it guarantees longer utilization of the landfill in future.	Concerns only the landfill. Waste diversion can potentially extend the landfill lifespan for years or even decades.	Higher degree of waste diversion contributes to saved landfilling space at Álfsnes and improves cost-effectiveness. Moderate significance.
2.12 Landscape	Not very sensitive to changes and not the center of the focus in this approach.	Concerns only the landfill.	Minor significance.

Annex 7. ARVI impact reasoning sheet for cost-effective waste management alternative of Àlfsnes (ARVI 2014).

Environmentally friendly alternative			
Impact	Sensitivity	Magnitude	Significance
1.1 Environmental stress	Environmental stress has to be minimized by decreasing the quantity of landfilled organic waste, long-lasting materials such as metals or hard plastic and by optimizing the waste transportation.	Water systems, nature, birds and mammals in and around the landfill. Gas emissions extend up to atmosphere, liquid emissions can be carried further away in sea water.	The landfill should not pose environmental or socio-economical stress to its surroundings, it should at least remain neutral. If the influence is not measured, this should be improved in future.
1.2 Climate and air quality	Climate is affected mostly by greenhouse gas emissions from the landfill. Increased organic waste landfill is not expected as it would contribute to increased emissions.	Odors rising from the landfill affect the immediate vicinity of the landfill, and greenhouse gas emissions are prone to having a much more widespread influence in climate.	Impact on climate and air quality is especially important to surrounding living areas but on a wider scale less emissions to atmosphere contribute to the prevention of climate
1.3 Water systems	Ground water and sea next to the landfill are at least theoretically vulnerable to pollution by leachate leakage or water run-off from the waste mound.	Landfill affects the water resources in its immediate proximity.	Leachate and contaminated water run-off from the landfill to surrounding water systems should be prevented at all costs.
2.1 Affordability	Minor investments estimated at least for better control of organic waste. More new investments make the alternative less affordable. Moderate sensitivity.	Financial input is not only needed at the landfill but also to fit the other facilities of SORPA for a desired waste management alternative.	Minor significance.
2.2 Applicability and technical potency	Minor technological changes are likely to be needed. Minor sensitivity, depending on the magnitude of expected waste diversion.	Concerns only the landfill.	Significance rises when larger and more complicated applications are planned for the landfill.
2.3 Maintainability	Álfsnes landfill is maintainable as proven by recent years without any drastic changes in the landfill structure. Bigger changes inside the landfill or SORPA's waste management system could result into a change.	Concerns only the landfill.	The waste management system has to be designed so that it remains functional for longer periods.
2.4 Waste availability	Higher fraction of environmentally harmful waste is excepted to be diverted. Low sensitivity, waste is excepted to be available for most instances.	Concerns the landfill, arriving waste from Gufunes and collection network.	Minor significance to make all the waste treatment options functional to maximize the environmental benefits.
2.5 Public acceptance	The reception of new waste management principles in public depends on the magnitude of changes and how much public is required to give its input to make the new waste management	Extends to the municipal households and small businesses which would be influenced if e.g. stricter waste separation rules would be implemented.	Moderately significant as this alternative would most likely require the highest input from municipal households and small businesses.
2.6 Level of change required	Changes are required to improve the system towards an environmentally friendly approach but the functionality of the landfill will not be compromised. Most vulnerable to changes out of all the examined alternatives.	Certain financial investments would have to be made to implement the cost-effective alternative, e.g. collection vehicles with multiple collection compartments and/or optical sensors to automatize the waste separation before landfilling.	Moderately significant, both the participation of public and minor investments in landfill/waste collection operator's end is required to make the system functional.
2.7 Landfill outputs	Possible outputs which the landfill is producing. Currently they are compost, metan gas (CH4) and gravel.	Concerns only the landfill.	Larger amount of landfill outputs is a surplus especially when it is profitable but output production should not compromise waste diversion from the landfill.
2.8 Living conditions	Neighboring residential area of Álfsnes landfill suffers occasionally from odors coming from the landfill. Increased landfilling of solid waste is likely to increase unwanted odor emissions.	Extends to the surroundings of the landfill, no further than 5-10 kilometres.	It is important to take to an account how the surrounding environment is influenced by the landfill. Every citizen has a right to clean air and water, no matter where they live.
2.9 Traffic	Traffic to, from and in the landfill is currently moderate. Increased waste quantity would likely lead to increased traffic.	Concerns only the landfill.	Lesser traffic to the landfill could contribute to decreased environmental impact. Moderate significance.
2.10 Employment	Concerns not only the landfill but also the other facilities of SORPA. Currently the waste management scheme is estimated to grow, so the employment is steady for now. Low sensitivity, not compromised in this alternative.	Concerns the landfill and other facilities of SORPA as waste diversion and its effectiveness is partially dependant of competent employees who actively contribute to manual labor.	Significant as a company cannot run itself without a sufficient amount of competent employees. Reducing employees is also likely to act as a demotivating factor to remaining employees.
2.11 Land use	Low sensitivity. More saved space contributes to extended utilization of the landfill in future.	Collected solid waste volume is directly related how much of MSW is landfilled in the end. Concerns only the land area used for landfilling.	Landfill has a maximum filling capacity and it should not be exceeded.
2.12 Landscape	Increased landfilling of solid waste would increase the changes in landscape. It is important to modify the landfill so that it does not pose an environmental threat. Esthetical outlook of the landfill is also important.	Concerns only the landfill.	Esthetical outlook of the landfill as well as not posing an environmental threat to landfill environment and its surrounding are both important features. Landscaping might improve the appearance of the landfill.

Annex 8. ARVI impact reasoning sheet for environmentally friendly waste management alternative of Àlfsnes (ARVI 2014).

Balanced alternative			
Impact	Sensitivity	Magnitude	Significance
1.1 Environmental stress	Environmental stress is likely to change along the improvements in the landfill, decreased stress by waste diversion is desired.	Water systems around and in the landfill, air quality and animals or plants in and around the landfill are not actively monitored except for odors generated in the landfill. Excessive measures are only taken if a problem arises.	The landfill should not pose environmental or socio-economical stress to its surroundings, it should at least remain neutral. If the influence is not measured, this should be improved in future.
1.2 Climate and air quality	Climate is affected mostly by greenhouse gas emissions from the landfill. Increased organic waste landfill is not expected as it would contribute to increased emissions.	Odors rising from the landfill affect the immediate vicinity of the landfill, and greenhouse gas emissions are prone to having a much more widespread influence in climate.	Impact on climate and air quality is especially important to surrounding living areas but on a wider scale less emissions to atmosphere contribute to the prevention of climate
1.3 Water systems	Ground water and sea next to the landfill are at least theoretically vulnerable to pollution by leachate leakage or water run-off from the waste mound.	Landfill affects the water resources in its immediate proximity.	Leachate and contaminated water run-off from the landfill to surrounding water systems should be prevented at all costs.
2.1 Affordability	How much financial input is needed for the system to make it work. More new investments make the alternative less affordable.	Financial input is not only needed at the landfill but also to fit the other facilities of SORPA for a desired waste management alternative.	Some investments are inevitable but the benefits in return should be Moderate significance.
2.2 Applicability and technical potency	Current technology and waste treatment methods are suitable and no changes are expected.	Concerns only the landfill.	Significance rises when larger and more complicated applications are planned for the landfill.
2.3 Maintainability	Álfsnes landfill is maintainable as proven by recent years without any drastic changes in the landfill structure. Bigger changes inside the landfill or SORPA's waste management system could result into a change.	Concerns only the landfill.	The waste management system has to be designed so that it remains functional for longer periods. Moderate significance.
2.4 Waste availability	Currently solid waste is available at all times and for all the functions of the landfill in Álfsnes.	Concerns the landfill, arriving waste from Gufunes and collection network.	Minor significance.
2.5 Public acceptance	The reception of new waste management principles in public depends on the magnitude of changes and how much public is required to give its input to make the new waste management.	Extends to the municipal households and small businesses which would be influenced if e.g. stricter waste separation rules would be implemented.	Actions to improve landfilling and waste diversion should not be so radical that it would rise opposition in public. Minor significance.
2.6 Level of change required	Changes are required to improve the system towards a balanced approach but the functionality of the landfill will not be compromised.	Extends at most to the municipal households, Gufunes plant and Álfsnes landfill.	Supposedly closest alternative to the current situation of Álfsnes landfill. Seeking for a solution between two previous alternatives. Minor significance.
2.7 Landfill outputs	Possible outputs which the landfill is producing. Currently they are compost, metan gas (CH4) and gravel.	Concerns only the landfill.	Larger amount of landfill outputs is a surplus especially when it is profitable but output production should not compromise waste diversion from the landfill.
2.8 Living conditions	Neighboring residential area of Álfsnes landfill suffers occasionally from odors coming from the landfill. Increased landfilling of solid waste is likely to increase unwanted odor emissions.	Extends to the surroundings of the landfill, no further than 5-10 kilometres.	It is important to take to an account how the surrounding environment is influenced by the landfill. Every citizen has a right to clean air and water, no matter where they live. Moderate significance.
2.9 Traffic	Traffic to, from and in the landfill is currently moderate. Increased waste quantity would likely lead to increased traffic.	Concerns only the landfill.	Minor significance.
2.10 Employment	Concerns not only the landfill but also the other facilities of SORPA. Currently the waste management scheme is estimated to grow, so the employment is steady for now. Low sensitivity, not compromised in this alternative.	Concerns the landfill and other facilities of SORPA as waste diversion and its effectiveness is partially dependant of competent employees who actively contribute to manual labor.	Significant as a company cannot run itself without a suffiecient amount of competent employees. Reducing employees is also likely to act as a demotivating factor to remaining employees.
2.11 Land use	More saved space contributes to extended utilization of the landfill in future. Low sensitivity.	Collected solid waste volume is directly related how much of MSW is landfilled in the end. Concerns only the land area used for landfilling.	Landfill has a maximum filling capacity and it should not be exceeded.
2.12 Landscape	Increased landfilling of solid waste would increase the changes in landscape. It is important to modify the landfill so that it does not pose an environmental threat. Esthetical outlook of the landfill is also important.	Concerns only the landfill.	Esthetical outlook of the landfill as well as not posing an environmental threat to landfill environment and its surrounding are both important features. Landscaping might improve the appearance of the landfill.

Annex 9. ARVI impact reasoning sheet for balanced waste management alternative of Àlfsnes (ARVI 2014).

Annex 10. Impact significance chart of the evaluated alternatives in ARVI tool displaying the distribution of impacts by their significance. The significance of impacts in each alternative are estimated on a scale from negative (very high or ----) to positive (very high or ++++) in relation to the current landfilling setup (ARVI 2014).

Significance	**Current setup**	**Cost-effective alternative**	**Environmentally friendly alternative**	**Balanced alternative**
Very high				
High		- Affordability	- Environmental stress - Climate and air quality - Water systems - Landfill outputs - Living conditions	
Moderate	- Climate and air quality - Water systems	- Environmental stress - Maintainability - Level of change required - Landfill outputs - Employment	- Traffic - Land use - Landscape	- Environmental stress - Climate and air quality - Water systems - Affordability - Maintainability - Landfill outputs - Living conditions
Low	- Environmental stress - Applicability and technical potency - Maintainability - Waste availability - Public acceptance - Landfill outputs - Living conditions - Employment	- Traffic - Land use	- Waste availability - Public acceptance	- Waste availability - Level of change required - Traffic - Employment - Land use - Landscape
No impact	- Level of change required			
Low	- Affordability - Traffic - Land use - Landscape	- Climate and air quality - Water systems - Applicability and technical potency - Waste availability - Public acceptance - Living conditions - Landscape	- Affordability - Maintainability - Level of change required - Employment	- Applicability and technical potency - Public acceptance
Moderate			- Applicability and technical potency	
High				
Very high				