

*Sweden:
Paradigm in sustainability*



Energy Recover in Sweden: a Case Study

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Abstract: Sweden has reached prominent figures both in waste management and reducing greenhouse gases emissions. Less than 1 percent of its municipal solid waste is landfilled, and the other 99 percent is harnessed by either recycling or producing energy. It helped the country's decarbonization, as its GDP raised 75% while its emission decreased 26% during the period 1990-2016. This is why the Sweden is a benchmarking either regarding waste management and economy decarbonization. This paper had the objective to identify key success factors that could inspire better practices in regulation and public policies regarding the energy and material recovering from municipal solid waste. To accomplish the goal it was held nine incineration plants technical visits, as well 19 Sweden experts were interviewed. It was delivered a overview of the stage of excellence of Sweden regarding waste and energy policies and 12 success factors were outlined. The key factors can be reunited in four groups: (a) holistic policy approach regarding diverse public demands; (b) integration of recycling and energy recovery from waste; (c) use of economic instruments such as taxes and tariffs in order to discourage harmful and incentive positive practices; (d) municipality's autonomy with economic and operational capacity. The key factors can also be useful lessons to decision and opinion makers of other countries to formulate strategies that can contribute to improve performance regarding proper waste destination and decarbonization of the economy.

Key-words: Waste Management, Decarbonization, Sweden, Energy Recovering, Waste-to-Energy, Low Carbon Economy.

Resumo: A Suécia alcançou números proeminentes tanto na gestão de resíduos quanto na redução das emissões de gases de efeito estufa. Menos de 1% de seus resíduos sólidos municipais são depositados em aterros e os outros 99% são aproveitados pela reciclagem ou para produção de energia. Isso contribuiu para a descarbonização do país, pois seu PIB aumentou 75%, enquanto suas emissões diminuíram 26% durante o período 1990-2016. Por conseguinte, a Suécia tornou-se um *benchmarking* em relação à gestão de resíduos e à descarbonização da economia. Este artigo teve como objetivo identificar os principais fatores de sucesso que poderiam inspirar melhores práticas de regulação e políticas públicas relacionadas à recuperação de energia e material a partir de resíduos sólidos urbanos. Para atingir o objetivo, foram realizadas nove visitas técnicas às usinas de incineração e 19 especialistas da Suécia foram entrevistados. Foi apresentada uma visão geral do estágio de excelência da Suécia em relação às políticas de resíduos e energia, e foram descritos 12 fatores de sucesso. Os fatores-chave podem ser reunidos em quatro grupos: (a) abordagem política holística em relação a diversas demandas públicas; (b) integração de reciclagem e recuperação de energia a partir de resíduos; (c) uso de instrumentos econômicos, como impostos e tarifas, a fim de desencorajar práticas prejudiciais e incentivar práticas positivas; (d) autonomia municipal com capacidade econômica e operacional. Os fatores-chave também podem ser lições úteis para tomadores de decisão e formadores de opinião de outros países para formular estratégias que possam contribuir para melhorar o desempenho em relação ao destino adequado de resíduos e à descarbonização da economia.

Palavras-chave: Gerenciamento de Resíduos, Descarbonização, Suécia, Recuperação de Energia, Resíduos-para-Energia, Economia de Baixo Carbono.

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1 Introduction

The current paper focus the Waste-to-Energy sector in Sweden in order to verify the transferability of the experience to other countries. Sweden is for a significant benchmark in various aspects. For instance, it balances high wealth standards (the 10 million inhabitants country is the 12th bigger world's GNP per capita – IMF, 2016), quality of life (14th Human Development Index - UNDP, 2015), and competitiveness (the sixth most competitive (Schwab et al, 2016)

Most of all, the country is well known by its commitment to the environment. Regarding the waste management, the country is one of the best countries in recycling as well in recovering energy from waste. It landfills less than one percent of its waste and moreover receive waste from abroad to produce energy (Bevanger, 2015).

It is therefore one benchmarking for most of countries that faces many challenges when it comes to waste management, especially for developing countries. For this reason, this paper examine the Swedish experience when it comes to energy recovery from waste.

2 Material and methods

Accordingly Yin (2003), the Case Study is the methodology better fitted to an inquiry one phenomenon when it is very complex, the researcher has low control of behavioral events and when it occurs at the same time of the research. One common topic of case studies is the evaluation of publicly supported programs such federal, state or local programs. Therefore, the methodology is proper fitted to the aim of this study as well framework. In this case, Sweden waste management and energy system frameworks are been seen as a benchmarking. According Blokland (2010), the benchmarking technique, after been used by the private sector to improve results, turned to be also essential in the policy making and public service regulation.

Therefore, this study gathered documents, testimonies and empiric data in Sweden in order to verify the central government and local government policy strategies that seeded and grew the recovering energy from waste still increasing the waste recycling. Besides, it was visited nine incineration plants (Malmö, Helsingborg, Borås, Kils, Kalskorga, Vasterås, Södertälje, Linköping and Jonköping) and 19 Swedish specialists were non-structured interviewed. The experts and institution are been listed at Table 1. All the interviews and the technical visits were been held in 2017.

Table 1- Experts interviewed.

Institution	Expert
NSR	Kim Ohlsson
Avfallsverige	Ann Carin Gripwald
Sysav	Lina Shahin
Oresundskraft	Martin Tofft
Goteborg Energi	Ingemar Gunnarsson
GMAB and	Per Lindgren
Business Region	Bernt Svensén
BEM	Linda Eliasson
Boras Hogskola	Professor Tobias Richards
Kils Energi	Jonatan Brunbäck
Karlskorga Energi	Per Lidell
Malar Energi	Tomás-Aparicio Elena
Mälardalens Högskola	Erik Dahlquist
Swedish EPA (Naturvardsverket)	Catarina Östlund
Söder Energi	Jan-Erik Haglund
Linköping Tekniskaverken	Henrik Lindståhl
Avfallsverige Intl	Stellan Jacobsson
Jönköping Energi	Ola Sjöland
University of Lund	Torleif Bramryd

3 Theory

According to United Nations Environmental Program the basic concept that underpins the waste management is the waste hierarchy (UNEP, 2013). Basically, waste hierarchy lists the actions towards management and reduction of waste in preference order. Generally it's presented in graphic form as in the Figure 1.

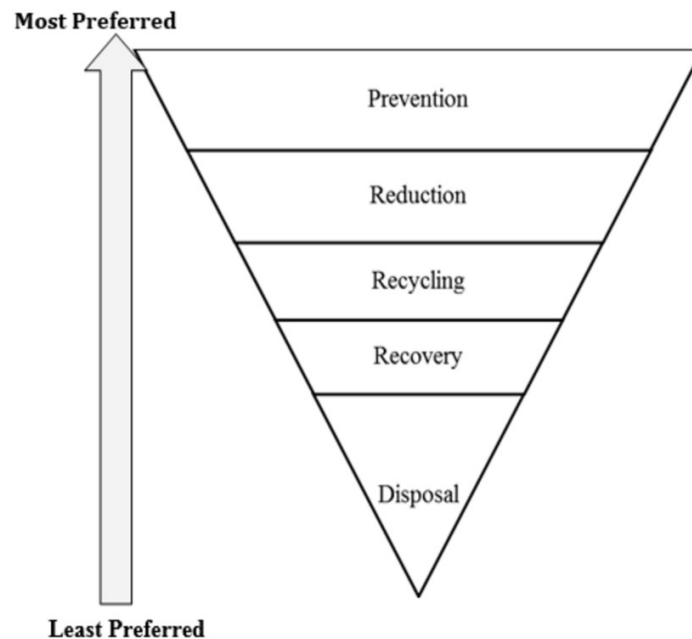


Figure 1 - Inverted pyramid with waste management hierarchy (Source: UNEP, 2013).

According to the hierarchy the priority order is up-down, being the waste prevention and waste reduction the first major actions, which avoid material and energy waste. Downstream there are recycling where some material and energy is wasted, energy recovering where there are some energy losses and material waste, and finally the landfilling, where both material and energy are wasted. In some cases there are the energy recovering of landfills through the collection and use of biogas, but with minimal efficiency. Naturally, it is not listed the developing countries' common practice of dumping the waste directly on soil or water bodies once it must not be considered as waste management.

Nonetheless, recycling and the upper steps of waste hierarchy save huge amount of energy of manufacturing process, there are two main ways of recover the energy contained in waste: the biological and the thermal route. The first one uses the microorganisms' action to transform the organic matter into a fuel gas, the biogas, and the second one uses directly the calorific value of the waste (Henriques, 2004). There is a little dispute about these routes, but they can be balanced in the energy mix and be both part of an energy plan (EPE, 2008).

3.1 Thermal Waste-to-Energy

The most consolidated technological route is the incineration, which can use two ways of burning waste: a) mass burning or grate-firing, where the material is directly put in a grate-fired boiler as burning fuel; b) fluidized bed

that requires a pre-treatment, but the pre-processed material, which provides better steam conditions will be delivered in return of higher costs for implementation and operation (Hasan and Ahsant, 2015). These techniques are very proven worldwide, but there also some developing thermal routes: gasification, pyrolysis and plasma gasification.

Incineration has been a traditional solution to avoid spread of infections and diseases, but as the cities get more populated, the waste management became more important and some municipalities start to use the incineration in a systematic way. In 1874, the English city of Nottingham installed the first systematic incineration of its refuse (Barbalace, 2003). Few years later, in 1885, New York built its garbage incinerator. According Clark (2003), throughout the late nineteenth and early twentieth centuries, most of expert sanitary engineers used to praise incinerators. However, yet during the 1910s started complains about the polluting effects (Clark, 2003). According the author, this process of enthusiasm and critics caused three different periods of incineration plants development in British history (1876-1914; 1969-1981; 1996-today). By the mid of 20th Century hundreds of incinerators were in operation in the United States. In 1994, Japan incinerated 74.4 per cent of its waste (Clark, 2003).

Although countries with lack of space as Japan have continuously improving the amount and technologies of incineration, the incineration plants have always received opposition mainly regarding the air pollution. However, the new technologies of increasing the burning efficiency and the flue gas treatment have changed significantly the facility profiles, which made the industry coin terms to distinguish themselves from the older and dirty facilities. Two terms are commonly used *Energy from Waste – EfW* (Howes and Warren 2015), and *Waste-to-Energy* (Reimann, 2012).

The *Waste-to-Energy* plants can delivery energy in various forms. In the United States, where there are about 80 plants in operation, around 74% produces only electricity, which sold in the grid; 5% generates steam and 21% produces both electricity and heat (Michaels, 2014). In Sweden, the main use is to heat delivering. About half of the domestic energy use in the country is for heating and water heating (SEA, 2015).

3.2 *Thermal Waste-to-Energy in Sweden*

In temperate climate country, people always had to find solution to face the cold climate at home. At first, each house had its proper heating system. Nonetheless, the cities got bigger and more concentrated. The great amount of individual systems along the cities was significant pollution source and, additionally, it was a wildfire risk. In order to address these issues, it was created the District Heating concept, which is a central heating source that is distributed to residential, commercial and industrial consumers for use in space heating, cooling, water heating and process heating. In Sweden, the District Heating inaugurated at Karlstad municipality in 1948. In Sweden, Waste-to-Energy plants relies basically on district heating (Magnusson, 2010).

Sweden started incineration and recovering energy in the beginning of the Twentieth Century (1904) but the major developments occurred after the Second World War and more properly after the 1970s' oil crisis and the climate awareness widespread when waste replaced coal to run centralized heating system (Williams, 2011).

In 1972, municipalities were assigned to collect and transport of domestic solid waste. Motivated also by the impact of oil crisis in 1973, the Swedish state decided to support program to investments focused on developing the energy recovery potential or other uses of domestic waste. The program introduced in 1975 as the same time municipalities developed District heating systems that could take advantage of the heat that incineration plants produced. In 1979, the municipalities became also responsible to the treatment of solid waste (Corvellec et al. 2011).

Waste concerns also led to a separation at source, which also saw a breakthrough in the 1980s. The Swedish government focused also in increasing recycling and reuse, enabling materials to be recovered from waste, and in preventing hazardous wastes going astray (Lundgren, 2011; Corvellec et al. 2011). In the middle of the 1980s, however, approximately 40-45% of the total amount of domestic waste went to landfills, approximately 45-50% incinerated (Rylander, 1985).

In 1990, the Swedish Parliament approved a national waste management strategy. From 1991 on, municipalities are required to have an acting plan for treating the waste, considering the waste found in the municipal area as a resource. Swedish municipalities have come under the obligation of laying down a detailed waste management plan, including information concerning waste and the municipality's measures to reduce the quantity and hazardousness of waste. The plans shall contain targets based on national environmental objectives. The municipalities' plans are coordinated by the county administrative board, which then analyses the waste treatment capacity and ensures the sufficient treatment capacity within the region (Corvellec et al. 2011).

In 1994 the Parliament stems the polluter pays principle, introducing the 'producer responsibility', scheme that requires quantified targets of collection and disposal of Swedish producers and importers of consumer goods packages, vehicles, newsprint, rubber tires and electrical and electronic equipment (Lundgren, 2011; Corvellec et al. 2011).

Swedish legislation had a milestone in 1998 with the enactment of the Environmental Code and especially Chapter 15 on waste management, formulating explicit rules for all relevant authorities. In 1999, the law on waste tax (1999:673) introduced the landfill tax scheduled to take effect by 1 January 2000 at a rate of 250 SEK/ton of waste (approx. EUR 27.5). The level of the tax was progressively increased and reached 435 SEK/ton (approx. EUR 47.9) in 2006 (SEPA, 2010). Under the Law on waste tax, all material entering landfill facilities is taxed, while material removed from the facility qualifies for a deduction. The tax is paid by the owner of the landfill on the basis of weight.

In 2001, The Swedish government issued the waste ordinance (2001:512) which banned the landfilling of combustible waste (from 2001) and all organic waste (from 2005) with only certain exceptions. Therefore, Sweden should have eliminated the landfilling of combustible and organic waste from 2005 on - or at least minimize it to the absolute necessary for waste that cannot be treated otherwise. Nevertheless, in the case that a region in Sweden is lacking the capacity to appropriately manage the treatment of the arising organic or combustible waste, the County Administrative Board has the right to grant a certain exemption from the landfill ban to that specific region (SEPA, 2006).

From 2001 on the waste management evolved steadily, with some ups and downs, and recycling rates reached an increase of 10 percentage points during the period 2001-2010. Material recycling rates have been considerably high due to efforts made in previous years, establishing well organized and operational producer responsibility schemes for different products

The year of 2005 was significant for the future vision of the Swedish waste management, once the Swedish EPA released the “Strategy for Sustainable Waste Management – Sweden’s Waste Plan”, that covered the next 5 years. At the same time, the Swedish government published its Environmental Objectives including specific targets for the reduction of MSW (SEPA, 2005). A challenging target was the 50 % recycling of household waste by 2010, which was almost met (Milios, 2013).

Along the period, the worst waste hierarchy step – landfilling – declined to an irrelevant share of the waste final disposition. The evolution of the regulatory waste management framework and its impact in the final disposition can be seen at the Figure 2.

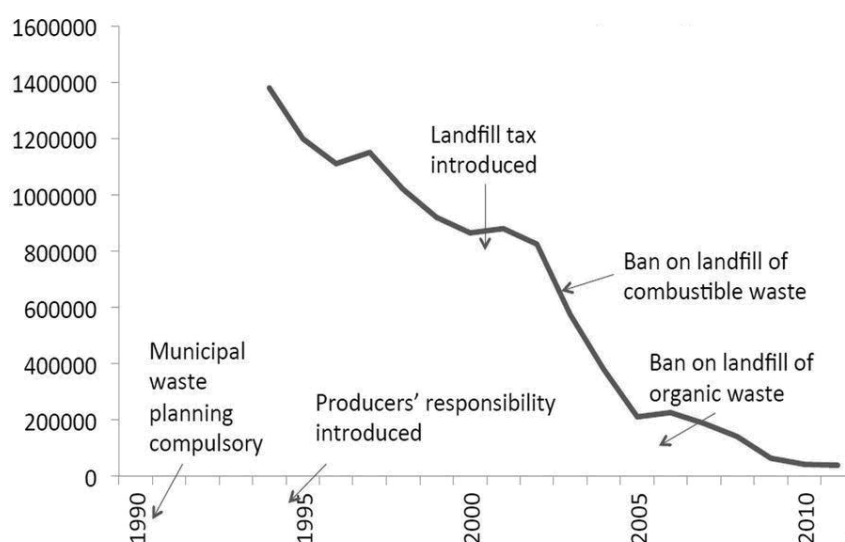


Figure 2 – Municipal Solid Waste landfilled in tons (Source: Gripwall, 2017).

There were in 2015, 34 heat plants using municipal waste and no incineration takes place without energy recovery. Almost all of them are combined heat and power plants, producing both heat and electricity. The power output is lower than in cogeneration plants that uses wood. However, municipal waste has to be treated all year around, and these power plants therefore operate for many hours. The plants are typical base load plants and most of the waste heat plants are located in large cities, to be able to take care of the produced energy all year around (Andersson, 2015).

Although measurements of Swedish waste shows that the ratio of biogenic content in the Municipal Solid Waste is around 58 percent, according to EU rules, only half of the energy in municipal waste can be seen as biogenic in the energy statistics. The fossil content is mainly plastics, but also synthetic rubber, synthetic fibers, paints, chemicals, etc. The use of 15 TWh of energy from waste means that about 4 percent of the final energy use in Sweden comes from solid waste (Andersson, 2015).

3.3 Results

Through the technical visits and the interviews, it could be noted different strategies used by the municipalities which has responsibility, under the Swedish Waste Management System, of any household waste that is not covered by producer responsibility. They are also responsible for restaurants, shops and offices. The responsibility includes the transport to recycling plants or disposal in landfills. It has being studied the responsibility of collecting packaging and recyclable plants that is - at moment - under producers responsibility. Anyway the producers must to be responsible for recovering the waste.

There are 290 local authorities (municipalities), which are directly elected and hold a strong position within the Swedish political system, including having the right to raise income taxes (Lönnroth, 2010). Every municipality is supposed to have its own waste (and sanitation) ordinance which consists of a plan and one framework regulation for waste management. The plan must include the way that the municipality shall take in order to reduce the amount of waste and the improvement of waste management. As the plan varies the strategies also differs.

3.4 Stockholm

Although Stockholm City have about 900.000 inhabitants, the Great Area of Stockholm is much bigger. Stockholm County, for instance, comprises 26 municipalities and it's the most densely populated counties of Sweden with more than two million inhabitants which makes more than one fifth of the Swedish population. Stockholm County Council is consisted of 149 members (Moktan, 2013).

Stockholm municipality and local laws regulates on waste collection, waste collection fees and disposal. Owners of each building have to pay the waste fee in order to gather money to finance the Waste Management in the city.

The fee covers costs of all the processes of waste disposal and gathering and also incineration tax and deposit tax (the whole process). The taxes is levied on the amount of waste sent to the incinerator plant and the amount of slag and ashes sent to landfill. In other hand, the incineration tax varies according to the electricity production: the higher electricity production is, lower is the tax. In contrast, the lower the electricity production is, higher is the tax. The tax value is calculated daily, and is declared to the National Financial Administration monthly (Zabaleta, 2008).

Paper and cardboard packaging, glass packaging, plastic packaging, metal packaging as well as newspapers and magazines is collected under producer responsibility and can be collected via collection points. The main collection system for separate collection of “producers package material” is unmanned public bring to 254 (in 2014) collection stations. The food waste sorting however has been implemented during the last years but in a slow pace. The collection of bio-waste in Stockholm was limited until 2014 with only 12% coverage for households and 36% for businesses.

In other hand, it had been a tradition to recover energy from waste, once the first decision of incinerating the main part of the MSW in Stockholm was taken in 1900, and soon the first incineration plant started to work in 1909. In 2007, for instance, almost the 100% of the MSW produced in Stockholm was incinerated (Zabaleta, 2008).

The biggest Stockholm incineration plant Högdalen plant has been generating energy from waste since 1970, but only when the district heating network grew in Stockholm, it was decided to turn Högdalen into a Combined Heat and Power-plant to produces both electricity and heat. The waste heated steam boilers was reinforced with an oil heated steam boiler with more two oil heated hot water boilers in 1979. In order to stabilize the system, it was also built an accumulator and finally the plant was connected to the local district heating network.

During the 1980s the plant's capacity continued to increase. In the 1980's an additional electricity boiler was installed and in 1986 a third industrial waste boiler was installed. The additional capacity stemmed from interventions in the follow years was based only in waste fuel: In 1999 boiler 6 was built to handle industrial waste and in 2005 the household waste boiler 4 was inaugurated. Additionally, the hot water boilers is shut down and boiler 5 that used to be fueled with fossil oil and now is now fueled with bio oil is inaugurated. In the plant there are two steam turbines for electricity production, G1 that was installed 1969 and G6 which was installed in connection to the construction of boiler 6 1999. G1 has an effect of 27 MW and the G6 an effect of 44 MW.

Högdalen power plant incinerates over 700,000 tons of waste, supplying some 100,000 households and business customers with district heating, and around 200,000 household customers with electricity. The Högdalen CHP-plant originally produced heat for the south district heating network in Stockholm, but the south district heating network was connected to the central district heating network in 2007, while the south district heating grid is also connected to Söderenergi's district heating network in further south. Initially, Söderenergi was created to provide

heat to the municipalities of Södertälje, Botkyrka, Salem e Huddinge, with three plants that could delivery, 2.450 GWh of heating e 213 GWh of electricity (they had a problem with one turbine in 2016). The Great Stockholm district heating system is very complex and comprises others municipalities supplied by other companies like the Finnish Fortum, the German Eon, Norrenergi and Vattenfall in a complex system of delivering heating.

The ownership of Söderenergi demonstrates how complex can be the shareholding in such kind of industry. The municipalities of Huddinge and Botkyrka have each one half of shares of an energy company called Södertörns Energi AB. In other hand, the municipality of Södertälje owns one other company named Telge AB. And these two companies, Södertörns Energi AB and Telge AB, share the Söderenergi. They share equally the influence and decisions, but Södertörns Energi AB have 58% of the assets' company and Telge AB 42%.

Söderenergi plant prioritize the use of fuels derived from used materials that cannot be reused or recycled in another more efficient way. Therefore the company used as a fuel, in 2016, 442 GWh of recycled waste materials, 1,291 GWh of recycled waste-wood, 145 GWh of wood-pellets, 572 GWh of forestry chippings and only 24 GWh of tall oil pitch and 34 of GWh of oil usually used in the plants startup. These figures picture 96% of waste and renewable resources as Söderenergi's fuel.

It was not always like that. In 1991, at Igelsta, the main Söderenergi's plant practically only coal was used to produce heat, but, from 1994 on, things starts to change towards less pollutant and renewable sources. Nowadays, the plant have three circulated fluidized bed boilers, the first one used recycled paper, wood and plastics not recyclable, in pellets. The second boiler produces heat using briquettes from wood and bark, and the third one uses recycled wood chips, pellets from recycled paper, wood and plastic.

The boilers can handle about 1,000,000 ton or 3,000,000 m³ of different kinds of waste fuels, but the quality of the fuel must be assured, so, besides careful contracts with about 40 suppliers – with about 50 % of the waste from abroad (UK, Norway, Netherlands and Germany) –, the company have an accurate quality control system with and automatized random sample collect equipment to verify if the residues have properties accordingly the contracts.

3.5 Gothenburg

Gothenburg is the second most populated city (around 600,000) in Sweden and invest in a sustainable appeal. The municipality have indeed a touristic product focused on sustainable solutions: Green Gothenburg (<http://www.greengothenburg.se/>) that offers visiting programs to the companies with recognized solutions. There are some packages available: Smart City Tour, Waste Safari, Electro Mobility, Smart Energy for Cities and one that gather Energy, Waste, Transport and Urban Development.

One main attraction is the Sävenäs plants which gather both the Göteborg Energi Cogeneration Plant and the Renova Group's Waste to Energy facility. The Renova Group, a waste management company, is owned by ten municipalities in western Sweden: Ale, Gothenburg, Härryda, Kungälv, Lerum, Mölndal, Partille, Stenungsund, Tjörn and Öckerö. The company have a permit to receive 550,000 ton of waste each year at Sävenäs, its waste to energy plant. About half of the waste comes from households and half from business and other activities.

The Sävenäs plant burns the waste in four furnaces, each with its own cleaning line for flue gases. The energy recovered provides district heating, which is delivered to Gothenburg's network, and electricity to the grid. It delivers 30 % of the heat for the regional district heating network and the equivalent of 5 % of Gothenburgers' electricity consumption, which represents: heating and hot water for around 150,000 apartments and electricity for close to 110,000 apartments each year.

The waste-to-energy plant runs 24/7, all year round to address waste production and energy consumption. Only in some days of summer, when the heating demand drops, the company repair and maintain the furnaces - one furnace at a time. The company bales combustible waste from businesses and other activities and store it until the heating demand rises, when the plant runs at full capacity again.

One critical issue to achieve efficiency and reduce the pollutants is controlling the fuel mix, air supply and the right temperature for the most efficient combustion possible. Random daily checks are carried out to make sure that the waste coming into the plant is being properly sorted. Regarding byproducts, waste that does not burn comes out of the furnaces as slag, which is sorted at Tagene facility that recovers approximately 10,000 ton of metals to be used as raw material. Also the bottom ash is recycled as building material. According its standard efficiency, one kilo of burned waste provides hot water for a 7-minute shower and electricity for 3 hours computer use.

Sävenäs waste-to-energy plant opened in 1972. Since then, the plant's efficiency and environmental impact have been improved, while continuously improving efficiency in delivery energy to the Gothenburg region. Currently the plant extracts three times the energy from each ton of waste comparing to the 1970s brand new.

When it comes to pollutants reduction, since 1980, emissions from the plant have fallen by between 90 and 99 % (according the pollutants), even considering the bigger volume of treated waste. Technology development to reach more stringent regulatory requirements improved the flue gas cleaning. Best sorting activities also had its role. Sorting and recycling are critical both to the cleaning and energy efficiency: for instance, hazardous waste needs to be separated out before it reaches the waste-to-energy plant. Different compounds in hazardous waste, such as heavy metals, are a problem for the cleaning stages. As well, gypsum/plaster, which contains Sulphur, should not be burned either. Food waste is better suited to produce biogas which recovers nutrients for soil. Packaging and

recycled paper should be sorted for recycling to new material. Sorting out plastic for material reuse instead of burning it in the waste-to-energy plant is one way of reducing CO₂ emissions.

Most of the waste burned in Sävenäs still comes from the Gothenburg region. But when it has idle capacity, it also receive waste from other regions and countries that could be going to landfills. The Gothenburg region's waste plan 2020 states that household waste per person in 2020 should not exceed the 2008 level - around 450 to 500 kg per person and year.

3.6 Malmö

The third biggest city in Sweden is Malmö (300,000) is located at the South of the country, separated from Copenhagen by the Öresund Channel. Its waste management service is covered by a company called Sysav. The company's complete name is indeed Sydsånes Avfallsaktiebolag and it is owned by 14 municipalities in southern Skåne: Burlöv, Kävlinge, Lomma, Lund, Malmö, Simrishamn, Sjöbo, Skurup, Staffanstorps, Svedala, Tomelilla, Trelleborg, Vellinge and Ystad. Yearly, each individual in Sysav's owner municipalities produced 276 kg per person came from municipal collections of household waste and 234 kg per person was left at a recycling center by residents. The permit of Sysav has licensed the company to use 550,000 ton of waste a year at its waste-to-energy plant. Yearly, Sysav submits an environmental report listing its operations, as well as environmental controls and inspections carried out by the supervisory authority. All other reporting regarding nonconformities in the operation are also sent to the supervisory authority.

The operations of Sysav itself encompass the management and treatment of household waste collected in Sysav's owner municipalities. Meanwhile other subsidiaries act in distinct areas as industrial and commercial waste, other municipalities' waste, Research & Development, recycling among others. During the year of 2015, 42.5% of the incoming waste in the Group was recycled as materials and 55.5% was recovered as energy and only 2% was sent to landfill.

Sysav has four waste sites and one waste station, distributed along the Sysav region. Processing, sorting and reloading of waste take place at these sites. The most important site is where the incineration plant facility is located: Spillepeng. It's an artificial peninsula at north of Malmö that extends a small way out into the Öresund Channel (which separates Denmark from Sweden). It is the only waste site in Sweden to be constructed through reclaiming land from the sea. Spillepeng has facilities for fuel preparation and sorting of slag as well as storage for combustible waste, landfills either for hazardous and ordinary waste. Next to the site there is an industrial area, a recreation area and a nature reserve with abundant birdlife. During summer, the demand for district heating drops, and thus Sysav's waste-to-energy plant uses less waste and thus the company stores combustible waste in the ground and packed down using compactors.

In Spillepeng, Sysav has a pre-treatment plant for food waste. Due to their consistency, food waste can be difficult to burn in Sysav's waste-to-energy plant. Hence, these wastes are mixed together and processed at the pre-treatment facility, to obtain a proper substrate to anaerobic digestion. Such substrate is delivered to a biogas plant 90 km away. In the same place the Sysav's incineration facility comprises four boilers. The two first hot-water boilers came into operation still in 1973 to produce district heating. Although old, the boilers and the system for cleaning flue gases have been reconditioned and updated in line with heightened demands on waste combustion. In 2003 came online the first modern steam boiler and in 2008, the second one. As a whole, Sysav is permitted to use 630,000 ton of waste a year as fuel. With such waste, the plant produces approximately 1,400,000 MWh of district heating a year, which roughly equates to the district heating of 70,000 small houses. The two new boilers produce 250,000 MWh of electricity each year.

Nonetheless there are significant differences among the two old hot-water boilers and the two new steam technology facilities, both of them deliver energy and its emission are continuously monitored from the central control room where operating personnel monitor combustion, the production of steam, electricity and district heating, and the cleaning and treatment processes. The emissions are measured, recorded and monitored to ensure the operation meets the environmental requirements. Measurement and registration are permanently, through installed instruments which show data both locally and in the control room. There are set templates for daily and monthly parameter reports.

The older boilers use water in the hot-water boilers which is heated to 150°C and passed to the district heating network via two heat exchangers. The flue gases also are led to an economizer where further heat is recovered. The flue gas cleaning system has several stages with both dry and wet cleaning. In the first step ammonia water is sprayed directly into the boiler to reduce nitrogen oxides. Then lime is added to neutralize acidic substances. A textile bag filter separates lime and dust particles. The bag filter is essentially made up of long, suspended tubes where the flue gas, pressed in from beneath the filter, flows, while the dust remains on the outside. The flue gases are then sucked into the wet cleaning process where pass through a four-stage scrubber. The first two stages remove chlorides, hydrogen fluoride, metals and ammonia while the third stage removes sulphur dioxide, and the forth is the water condensation stage. Each stage involves a bed of carbon-saturated filling material which absorbs dioxins and increase the contact surface between water and contaminants.

The two modern steam boilers use "state-of-art" mass burning technologies. They have a joint waste bunker where the refuse collection vehicles tip the waste, where one travelling crane - operated from the control room - grabs and lifts the waste into the chutes that feed the boilers. The furnace comprises an inclined grate with an area of just over 100 m². The waste slides down the reverse-acting type grate, where it is dried, evaporated and combusted. The bars of the grate push the waste upwards and downwards to remix it, ensuring its optimum combustion. In order to ensure the combustion being efficient and complete, combustion air (primary and secondary) is blown

into the furnace. Fans are used to push the primary air between the bars of the grate beneath the fuel bed, while secondary air is added above the fuel bed to help mix the flue gases properly to achieve optimal combustion. Normally, the temperature in the furnace is over 1,000°C. During ignition and extinction or when the waste's energy level is not high enough to maintain the correct combustion temperature, auxiliary combustion with oil is used, but during normal operation the furnace is only fed with combustible waste. The waste which has passed through the grate became slag, which is tapped off into a bunker for subsequent sorting and recycling.

The flue gases formed during the combustion process pass three vertical empty ducts with tubes on the walls where the temperature is high. The function of the empty ducts is to achieve complete combustion of the flue gases. The flue gases - with a temperature of 850°C - heat the boiler water circulating in tubes. In the horizontal part of the boiler - convection tubes and super-heaters - the water reaches its highest energy value here at temperature of 400°C and a pressure of 40 bar. The steam from the boiler is conveyed to the turbine which run a generator. Part of the electricity produced is used in the plant, while the rest power distribution grid. After that, the steam is directed to a condenser where it is used to heat district heating water. The condenser is a large heat exchanger, that condensate the steam as the heat is transferred to the district heating water. The water is then pumped back into the boiler's water/steam system.

The district heating water is heated to between 80 and 115°C depending on the outdoor temperature. When the district heating water returns to the plant with a temperature of 40-60°C, heat is extracted, increasing the temperature of the district heating water with 5-10°C. The building's waste heat is also collected through heat pumps. The flue gas is additionally cooled with heat recover before it is let out through the stack.

Regarding the flue gas treatment, the first stage of cleaning, an electrostatic precipitator removes the majority of the dust. A negative electrical charge is given to the dust when it pass emission electrodes. Precipitation electrodes - metal with a positive charge - are located between the emission electrodes. These electrodes attract the negatively charged dust particles. The sheets of electrodes are mechanically shaken at regular intervals and the dust falls into a pocket. When the flue gas leaves the electrostatic filter the dust content is less than 20 mg/m³. The dust particles are collected and safely deposited for final storage. Each 100 kg of waste generates approximately 3 kg of ash and sludge remain after combustion.

Other cleaning stage for the flue gases is the electroventuri filter, which works in similar way of electrostatic precipitator but in a wet environment. This is where any remaining dust in the flue gases is removed. The electroventuri filter comprises 24 pipes. The dust particles are negatively charged by an electrode and then absorbed by positively charged water spray. The water with dust is directed to the water treatment plant via the acid scrubber.

The final stage of the flue gas cleaning process is the catalyst, which treat nitrogen oxides. In the catalyst, the flue gases pass through a fine ceramic material and ammonia water is injected. The nitrogen oxide reacts with the ammonia is reduced to nitrogen and steam. The water from the scrubbers and the electroventuri filter are treated by adding chemicals that make heavy metals and other contaminants precipitate in a series of tanks where they form a sediment and are concentrated into a sludge.

3.7 Västerås

In Västerås the energy demand was the drive to Waste-to-Energy initiative. Although in many municipalities waste-to-energy as a primary response to the waste issue, some municipalities, started to use the technology to supply its energy demand. It's the case, for instance of Västerås, one industrial municipality with history closely related to the power industry.

Västerås is a municipality 115 kilometers distant from Stockholm in Västmanland County. It is the Sweden's sixth biggest city and has around 140,000 inhabitants in the extended area. It is also a kind of cradle of modern Sweden, once it was there that the first king of Modern Sweden, Gustav Vasa held two parliamentary sessions that changed the future of Sweden there. One parliamentary session in 1527 abolished Catholicism and in 1544 established the hereditary monarchy. Also Sweden's first upper secondary school was founded in Västerås in 1623.

Västerås also was protagonist during the Swedish industrialization. The energy service, started before, still in 1861, but at that time just the original company supplied city lighting with 40 gas lights. It was during the second industrial revolution when it was started the delivery of essential services as water management and electricity, that the municipal public service company became more and more relevant as the city became progressively industrialized. The main municipal industry indeed is close related to the electricity market development: ASEA (which lately became ABB) was headquartered there.

The introduction of district heating in Västerås took place in 1954 and in 1963, the current plant of Kraftvärmeverket was opened. In 2000 Mälärergi was formed by merger of some cities' utilities service companies and the company start to expand their services to other municipalities as Hallstahammar, Kungsör and Surahammar. Nowadays the company owned by Västerås municipality comprises about 700 employees, and accounts approximately SEK 3 billion revenue.

The plant Kraftvärmeverket started its operation in 1963 as a two boilers conventional district heating plant. In 1969, the block 3, one combined CHP power plant, is put into operation. One fourth boiler was commissioned in 1973 with a combined heat (365 MW), power (220 MW) and condensing (250 MW) plant that was originally built to be oil-fired. The oil crisis of 1970s causes the switch the fuel of the two first blocks from oil to coal in 1981 and the same occurred to block 4 in 1983. In 1992, the city was the first Swedish one to delivery also cooling. In 1998,

started the migration of the boilers to low carbon and renewable fuel: the first blocks (1,2 and 4) were converted to use black liquor which is a renewable byproduct of pulp and paper industry. In consequence, the fourth boiler firing so reduced the capacity for 155M of electricity, 250MW of heating and 180 MW of electricity in the condensation. Since 2002, the fourth boiler has also been possible to be fired with wood pellets or peat, keeping the same capacity. In the same year of 2000 when utility companies were reorganized into Mälärergi, the company built the fifth biofuel boiler that altogether with the fourth replaced the fossil fuel at the base charge and the fossil boilers became used only during the peak load. The overall biomass power and heat production of (boilers 4 and 5) comprises 210 MW of electricity and 400 MW of district heating with a condenser operation of 250 MW of electricity.

Only in 2014, it was built the boiler sixth that is fueled by waste. The Block 6 is the bigger and most important, once accounts for about half of total Västerås District Heating consumption, and it can handle more than one type of fuel, we get a great deal of flexibility when it comes to changes in the fuel market. But the main fuel (they are remunerated for it) is waste from the region's households as well as imported household waste. The introduction of waste in the fuel mix reduce emissions of fossil carbon dioxide by about 300,000 ton per year comparing to peat. This corresponds to the emissions from 100,000 cars.

The Mälärergi waste-to-energy plant (Block 6) uses the fluidized bed technology. So the waste have to be pre-treated before goes to the boilers. From households and industries, shredded combustible waste comes into the plant's fuel reception where they are checked before the waste is tipped into the first reception bunk, waiting to be prepared. Above the bunk there are two large gratings that mix and sort the waste to make it as homogeneous as possible.

The grips carry the waste to the crusher, named as Tyrannosaurus, which cuts the waste to little pieces. After that, metal is sorted out and sent to recycling. Heavy materials, such as stone, glass and ceramics, are removed and sent for recycling or landfill. Once the fuel is ready, it is passed into the boiler (other building) on the closed conveyor belt.

The fluidized bed boiler filled with sand (which comes from Småland) in order to achieve even temperature and more efficient combustion burns about 60 ton of waste per hour and the fire heats 135-degree water to water vapor, which is passed through the heat from the flue gases and further through the sand bed and finally the steam reaches 470 degrees. As a whole, the plant that recovers energy from 480 kilo ton per year of sorted Municipal Solid Waste and delivers 50 MWe power and 130 MW district heating.

The flue gas purification uses activated charcoal, lime and water that form particles with the fumes of the flue gas acid and heavy metals. Through a huge hose filter, the particles are filtered off and sent away as hazardous waste. The residual flue gas is purified by water. The cleaning process makes water warm, and this heat sends us to the

district heating network. The water is reused in the beginning of the flue gas treatment and a small amount of purified water is led into the lake Mälaren. The remaining smoke gas is always tested before being transported through the 110 meter high chimney.

3.8 Linköping

Linköping, a 100,000 plus inhabitants city, is known by locate the aviation company SAAB. The municipality strategy is to put in charge one big municipality own company (Tekniska Verken) to delivery all municipal public services, as electricity, public lighting, water, waste water, heating, biogas, biomethane, internet and additionally energy consultant. Although the company is owned by the municipality, it was a private company by the end of the Nineteenth Century. The District Heating of the city was inaugurated in 1954. In 1959, the company started to deliver waste management. Only in 1982, the company started to produce heating from waste in its Gärstad plant. From 1997 on, the plant began to deliver also cooling from waste. In 2005, at the same local, the company built the huge and modern incineration plant and, in 2016, it was ready its twin facility.

So, the Gärstad complex comprises five production lines: the older facility house three boilers (Panna 1,2 and 3). They are all hot water boilers. The first one has 15 MW capacity, while the second and third have each one 30 MW. The steam produced by these boilers delivers both steam and electricity (10MW) or only steam. The plant also hoses one oil auxiliary boiler.

The first modern boiler (Panna 4) use steam to simultaneously produce heat and electricity. One 19MW reverse pressure turbine uses steam to produce electricity. The heat capacity of the boiler is 68 MW, with flue gas condensation and heat pump that can be recovered. The newer one (Panna 5) produces 84 MW, with additional 12MW (condensation) and 21 MW of electricity produced by another reverse pressure turbine. In order to achieve maximum flexibility, there is one steam line connecting the boilers. This flexibility allow the company to use different fuels and outputs, according fuel prices, taxes, and other factors.

Together, all boilers can treat 420,000 ton yearly of sorted waste. These facilities operate on the basis while the peak consumption is supplied by other little plants Kraftvarme (close to the central station in the central area) and Tornby. The Linköping District Heating system is connected to the systems of the neighbouring cities Mjölby, Ljungsbro e Lingham. Nevertheless, the high capacity of the new boilers brought one new issue to the company: the best energy use. Once the waste has to be treated all year along, but the heating demand is much higher on winter, it will be desirable one way to storage the energy. The company is working on it.

The flue gas monitoring comprises all the facilities. The emission data are monitored continuously by control and process monitoring tools. The real time data is transferred to one Excel file that stems internal and external reports.

If there is a cleaning equipment problem that incurs overcoming the legal standards, one automatic clock starts to inform the control staff how much time the fail will persist before the boiler shut down.

3.9 Helsingborg

Helsingborg has almost the same population of Linköping, but its strategy is opposed. Instead of a huge company with several branch, the Waste Management Company decided to focus on the issue and, more than this, sought to private partners in order to improve the circularity of waste management. The company called the cluster initiative as Vera Park. Thereby, Vera Park is a Sustainable Business Hub that comprehend 14 cleantech companies in the region of Helsingborg. Besides the companies also are part of the initiative the academy and the public sector, as the objective of Vera Park is establishing one network and a collaborative way of exploring new markets domestic and abroad.

The vision of the initiative is become one leading center in Europe in circular economy regarding innovation and research which leads to increased recycling and reuse of waste. It will also lead to export of products and services in waste management. Vera Park congregates the following companies: NSR, the collect and recycling company of Öresundskraft AB, the Energy regional utility; the international consultancy company WSP; OX2 Production AB, an international renewable energy company; TMR, a collecting and recycling company; Ohlssons AB, the regional logistic services leader, KAABS Nordic AB the regional leader of scrap recovery;; GAIA Biomaterials, bio and degradable materials producers; Ragn-Sells AB, a company focused on waste management, environmental services and recycling; ENVIR, focused on waste composition analysis; OCO Nordic, an ice cleantech company that use ice blasting as cleaning tool, LBG AB, which produces biogas from organic waste streams; FEAB Partners AB, a cleaning services company; iTunnan AB, a producer of plastics solutions for waste collecting. The University of Lund also participate of the initiative, through the Department of Service Management and Service Studies.

Nordvästra Skånes Renhållning (NSR) s the leading company and it was created in 1982 to handle the region's municipal and industrial solid waste. It is a public company owned by the municipalities of Helsingborg, Bjuv, Båstad, Höganäs, Åstorp and Ängelholm. Initially its function congregated collect and sort waste, produce biogas, take care of recycled and reusable material, send the burnable waste to incineration, or place it in landfills. But along the time, the company has privatized many of these functions, keeping, however, the companies working closely in a collaboration scheme.

For instance, the incineration waste-to-energy plant of Filbornaverket was built by Öresundskraft on the property of NSR as a collaboration. Öresundskraft is one leader company in Sweden regarding energy delivery. It is owned by the municipality of Helsingborg and runs six production plants in Helsingborg and four in Ängelholm. The

most important plants are Åkerslund, Filbornaverket and Västhamnsverket. These plants supply Helsingborg with heat, cooling and electricity. Filbornaverket is one of the most modern waste-to-energy plants in Europe and has very low emissions.

Although they are different companies, they still work closely together under Vera Park scheme. Consequently the company could better focus to its core business which is collecting and sorting. The waste sorting system NSR is known to be able to process and send large amounts of sorted waste, such as paper, plastics and other recycled materials. It makes one big Europe supplier but the company aims to build one circular economy within the Helsingborg's area, which will make the chain more sustainable and enhance the region economy.

3.10 Jönköping

Jönköping is a city situated at the southern end of Sweden's second largest lake, Vättern. It has a population of almost 100,000 inhabitants, which is warmed by the District Heating supplied by the Torsvik combined heat and power (CHP) plant, developed by Jönköping Energi AB, that was put into operation in 2006. The plant uses a grate type boiler to combust 162,000 tonnes per year.

Torsvik is designed to produce 350 GWh of heat and 100 GWh of electricity annually, with an overall plant efficiency of 92% and in conformity with the Waste Framework Directive energy efficiency criteria. The heat is delivered to the district heating network in Jönköping and Huskvarna, which supplies around 30,000 households and municipal localities in these communities. The Torsvik plant covers half of this heating demand. Electricity produced is fed to the grid.

The municipal waste burned at the plant can be sorted or mixed combustible waste depending on the community where it originates. In Jönköping, source sorting is gradually being implemented and food waste is separated from other combustible waste. The food waste is converted to biogas and bio-fertilizer. The biogas is used in vehicles while the bio-fertilizer replaces synthetic fertilizer.

Waste fuel delivered to the Torsvik plant is dumped in a 17,000 m³ bunker. The fuel is a mix of 40% municipal solid waste and 60% industrial waste, with an average heating value of 11.7 MJ/kg.

3.11 Borås

Borås is a Swedish city nearby Gothenburg founded in 1621. It shelters approximately 110,000 inhabitants (Sweden's 13th largest city) and more than 11 500 companies. It is well known for being a textile city. Energy management in the city, started at the end of nineteenth century, in 1894, the town council took the decision to erect a municipal steam-driven. In the same year, the first electric light was lit in Borås with power from the

municipal generating station. Telegraphy and lighting were the primary area of use for electricity. Long-distance power transmission at the end of the century, helped Borås to take advantage of falls at Häggårda, Hulta, Haby and Axelfors to obtain great amounts of surplus power at its disposal. For a long time the city enjoyed the highest per capita electricity consumption in Sweden. When electricity also began to be used to power machinery a major development took place in Borås' textile factories. Belt and pulley systems were removed and replaced by electric motors driving individual machines, creating a more efficient and friendly facilities.

Once Sweden demand a lot of heating, soon several cities started to realize that Swedish hydroelectric power must be supplemented with thermal power. Borås did not take a long time to have initiative. Still on December 1957, the city decided to build a district heating grid that was commissioned in 1958, first fueled with oil, but soon, in the next decade, waste became fuel to the system as well. Since then the grid has expanded and in 2010, the district heating produced 751 GWh to serve around 35,000 inhabitants. At the beginning of 2011 there were approximately 300 km of district heating pipes and 4,299 customers. Currently, the municipally owned company Borås Energi och Miljö (BEM) formed 2006 manages not only heating, but also power production, sewage, waste management and biogas.

Ryaverket, the main supplier of district heating, started to be constructed in 1965 and over the years the plant has been modified several times towards a more clean and efficient production. In the beginning, production was mainly based on fossil oil and it was burned only a small percentage of waste. The first two waste incineration furnaces were opened in 1966, and a third was installed in 1972. The first two furnaces were shut down in 1987 following a decision by the national electricity generating board. The third boiler remained in operation until 1991 and was then closed. In the 1970s, during the oil crisis, the city started to convert oil-fired combined heat and power generation in 1979 to coal and forestry chippings. In 1984 two large oil-fired boilers of Ryaverket were converted to burn solid fuel combining biofuel (75%) and coal, (25%). A dryer was installed in 1994 to allow boilers to be run on biofuel alone. The next stage of development would be to build a gasification plant. However, it was decided not to proceed with this project. After the ban of landfilling sorted combustible in Sweden, the City of Borås decided to build a new waste incineration plant at the same location as the old one. On July 2002, Borås Energi was granted a permit to build a waste incineration plant with a capacity of 100,000 ton per year.

Nowadays Ryaverket has a combined heat and power plant with two biofuel boilers, two waste boilers and two generators. There is also a back-up system with an electrical heater plus two LPG/biofuel/oil-fired boilers. The biofuel boilers are grate-fired steam boilers. Biofuel mainly comprises forest fuel as pellets and chips made from left-over materials of the forestry industry. Flue gases are cleaned by electrical filters connected to each boiler. Ash from the boilers is then used as a forest fertilizer.

The waste incineration facility which has two fluidized bed boilers and a modern flue gas cleaning technology, was opened in 2004, with two 20 MW boilers and a total output of 40 MW. They burn the combustible portion of domestic waste and combustible waste from non-domestic sources. The inhabitants of Borås sort their domestic waste and deposit it into differently colored plastic bags – white for combustible waste and black for biodegradable waste. Recyclables are separated and deposited at one of the company's five recycling centers (where it can be handed hazardous substances, demolition waste, green waste from gardening and recyclables) or the 80 recycling stations (packaging and paper). The different types of waste are then transported to treatment facilities. There is a huge waste management plant at Sobacken, ten kilometers away from the city where the black bags and white bags are automatically optically separated. The white bags are used as fuel for generating district heating and electricity, while the contents of the black bags are converted into biogas

After sorted and pre-treated, the non recyclable waste is transported back to the Ryaverket plant located at Borås central area, where the energy extracted to be transformed into district heating, district cooling and electricity. Although the Waste-to-Energy plant is located in the central area of Borås, according, there is no register of complains of the population regarding one waste incineration plant amidst neighborhood. To ensure incineration is complete and to guarantee low emissions, the boilers have start-up and support burners. The waste boilers' flue gas cleaning system comprises slaked lime and activated charcoal. Particulates are then collected in a textile filter before the flue gas is passed to the smokestack. Metals are sorted from the bottom ash the ash and used as construction material at Sobacken.

In order to ensure a sufficient amount of energy in the district heating grid, there are six smaller back-up and support plants located along the grid, which includes the two ones located at Ryaverket. Both boilers can run on LPG but, in 2007, one of them was converted to also run on bio oil. The remaining five plants, which run on fossil fuels, are only used in very cold weather or during scheduled and unscheduled maintenance at Ryaverket.

District heating is distributed via underground pipes to dwellings and companies in Borås and is used partly to heat water circulating through radiators, and partly for heating tap water. Once household heating requirements vary during the day - commonly the need for heat is bigger in the morning when many people want to take a shower, while demand is lower during the day when most people are at work. The accumulator tank, which works like a buffer, is used to meet the morning demand heating water supplied via pipelines to heat houses can be stored in the tank instead of firing up an extra fossil fuel furnace, reducing the requirement for fuel. As a support for the system, there is also a heat pump; it extracts heat from sewage water at the sewage treatment plant.

Currently energy production is based primarily on waste-to-fuels and biofuel. The current fuel mix in the Borås central district heating grid comprises 26,6 % of Waste(in base); 50,7 % of biofuel; 2,6 % bio-oil, 1,9 % of waste heat; 7,3 % of oil; 1,3 % of electricity and 1,0 % of recycled heat.



In 1996, it was installed a district cooling grid to provide its customers an alternative to air conditioning. The company produces up to 7,5 GWh of district cooling mainly at Ryaverket. There are two absorption chillers run by water from the district heating grid instead of electricity and brine is used to transfer the heat between the different media. District cooling is produced from surplus heat from the waste boilers through absorption chillers. Conventional technology is used only when there is no surplus available. Two conventional cooling units include heat recovery technology in order to exploit heat extracted from various buildings. Which means that all the heat transferred from customers to the district cooling water is recovered in the grid, including heat from the electric compressors in the conventional unit. The district cooling grid supplies industries, offices, malls with cooling to create indoor environments.

The two power generators at Ryaverket run with steam produced by the combustion of biofuel and waste produces most of the electricity produced at the city. In 2010, 147 GWh were generated at Ryaverket, and 33 GWh by the hydropower plants. The first generators were built in 1965, but were rebuilt and renovated in 2008 to obtain a higher electricity/heat ratio. Electricity generated at Ryaverket and the four hydropower plants is sold to the Nordic electricity market.

3.12 Karlskoga

Karlskoga is a small municipality in Örebro County, which about 30000 inhabitants. Its economy has been traditionally based primarily on iron and arms. In late Nineteenth Century, these arms became also cannons and artillery industry. One the key role in reshaping the iron manufacturer into a modern cannon manufacturer and chemical industry was played by Alfred Nobel owned the most important company (Bofors) from 1894 until his death in December 1896.

When it concerns to the public services strategy, especially when it comes to waste, the relatively small municipality have been articulating to be an hub that receive waste, produces and even export energy (in the form of biomethane) to the region, including bigger cities as Örebro (110000 inhabitants) and Karlstad (62000) inhabitants.

The strategy is based on a concentration on the public service activities. The municipality owned public service company Karlskoga Energy & Environment Group consists of a total of eight companies wholly or partly owned: the parent company Karlskoga Energi & Miljö AB with the five wholly owned subsidiaries (one electricity supplier, the waste incineration and recycling plant, the water and wastewater company, the broadband utility service provider, the hydroelectricity producer. As well the company has partnership in cleaning and biogas companies. In total, the group employ 180 people and its turnover is approximately SEK 500 million.

Karlskoga Kraftvärmeverk AB, located in the Björkborn industrial area produces and supplies district heating to private individuals and companies in Karlskoga and also supplies steam to industries in the Björkborn industrial area. The company also has Mosserud's recycling facility. Although district heating has been delivered since the late 70's – from smaller boiler plants previously deployed at various locations in Karlskoga – the Kraftvärmeverk main production facility in Björkborn was built in 1985. At the Kraftvärmverket, 50 people work. The plant supplies 360 GWh of energy per year. The district heating network is 108 kilometers long.

Karlskoga Kraftvärmeverk annually burns about 100,000 ton of waste, in which 60 per cent consists of waste from industries and other activities and 40 per cent are household waste from 14 municipalities in the region. Incineration of untreated household waste is carried out in a so-called roasting boiler. The combustion of shredded waste and animal waste is carried out in so-called fluidized bed (CFB) boilers, which imposes higher requirements on pre-treatment of the fuel than in combustion in roasting boilers. Common to both technologies is that the quality of the waste is of great importance to the combustion process. Notwithstanding emissions of pollutants are prevented by continuous optimization of combustion conditions and control of incoming waste, advanced purification technology is also applied. Karlskoga combined heat and power plants have dry flue gas purification on the pan and wet flue gas cleaning on the CFB boilers. During the wet treatment, additional heat is extracted in the purification stage and is supplied to the district heating system through so-called flue gas condensation. The process water from the flue gas condensation contains the separated pollutants and is purified before releasing to the treatment plant.

After the incineration of household waste, bottom ashes and flue gas residues remain. The bottom slag consists of non-combustible materials like metal scrap that represent 20% by weight of the amount of household waste. The material is sorted and used as material of road construction at Mosserud's waste disposal plant and as recycled material and metal scrap. The flue gas purification residue consists of calcium hydroxide used to separate pollutants from the flue gases and the dust in the flue gases. They correspond to about 3-5% by weight of the amount of waste supplied.

3.13 Kil

The smallest infrastructure visited of waste-to-energy and district heating was in Kil. Kil is a small municipality in Värmland County, Sweden with 12000 inhabitants (in 2010). Nevertheless the city is not very much concentrated, which makes the task of delivering heat a little complex. The company in charge of the task is the Kils Energi a municipality owned company with 8 employees, which produces about 40 GWh a year to supply approximately 620 customers. The company started its operation in 1983, but the first boilers Dalliden, installed in 1983 and Karlslund, installed in 1995 were, small (1.6 MW and 1 MW respectively) and at first fueled by oil, although nowadays they use pellets. But the main plant which made feasible the district heating is the Lersätters. A plant

with 9 MW capacity that uses annually 15000 ton of wood residue in chips was installed in 2003 with combustion technology BFB, dry flue gas cleaning and SNCR, control system Emerson, Siemens, similar to the waste-to-energy bigger companies. In fact, the plant can use municipal solid waste if necessary, but it increases significantly the operational costs, so the managers prefer to use the chips and rely its financial performance in long and favorable contracts.

It is important to keep the costs low to ensure the competitiveness face the main competitor: the heat pump. Besides the effort to keep the fee low, with lean team, high level automation and tight financial control, the company also offers a customer service center as a competitive advantage.

3.14 Discussion

From the empirical observation, interviews and literature review it could be found some key factors in the waste-to-energy and recycling framework in Sweden. Obviously some of them are very challenging, difficult or even impossible to replicate to other countries. Nonetheless they could orient, drive or even inspire decision makers in order to improve the waste management and harness the waste energy potential.

- a) The heating need. Due the temperate climate, Swedes always had to find a way to keep their dwellings warm. Nonetheless, the individual heating systems were extremely inefficient and caused a major problem: pollution. It grounded the necessity centralized heating systems in order to rationalize the use of fuel and minimize the environmental impact of heating supply;
- b) The concern regarding the energy security. After the oil crisis during the 1970s, the Sweden high reliance on imported oil until had to change and a lot of fuels were tested in order to replace oil. Biomass and waste were among the strategies. Nonetheless the oil price drop considerably during the 1980s, the country kept track on searching for alternatives. So waste-to-energy facilities swept along the country at that time;
- c) The trust on country's institutions. It was clearly verified when, in the middle of 1980s, some concerns about dioxins and furans emissions of waste-to-energy plants had been raised. The government set one Commission to study the issue and after a period the Commission released its decision: the technology was proper to deal with waste. The country's accepted the verdict demonstrating high level of confidence;
- d) The carbon tax. Since the middle of the Twentieth Century the Sweden Government tax the energy use. In 1991, within a comprehensive tax reform, the Parliament split the energy tax into two taxes: the energy and the carbon emission ones. This strategy gives one considerable boost to renewable sources of energy, once they pay only the energy share and gain competitiveness compared to others;

- e) The landfill tax. In turn to Twentieth One Century, in 2000, the country set one tax on landfilling, in order to reduce the energy and material waste comprised by its solution;
- f) The ban on landfilling combustible waste. After 2002, the country banned the landfilling of waste that had potential as combustible in order to minimize the waste resource in landfilling and increase the availability of waste as fuel to produce energy;
- g) The ban on landfilling organic waste. Although this initiative was mainly addressed to increase anaerobic digestion, it also contributed to incinerators, once the ban swiped once again the remaining landfilling activities;
- h) The policies, regulations and actions coordination. The energy recovery from residues would not ever be feasible if the economic approach were inside the box. It will be always a cheaper solution if one considers only a restricted stand of point. In order to deal with waste, it is cheaper to landfill or even dump it; in order to produce energy there are many available low-cost fuels and so on. But if one considers the whole impact and costs of each solution, it is possible to find a way of optimize the resources and find a way to enable solutions that results in gains under more than one aspect.
- i) The municipality economic and operational capacity under the State of Sweden. Under the Sweden tax system, the municipalities keeps the overwhelmingly major share of the taxes. Consequently, they had operational and economic capacity to deal with challenging questions;
- j) The state entrepreneurship. Mostly of the waste-to-energy companies in Sweden are state owned, although most of them are owned by more than two municipalities which makes the companies less liable to political influences. Nonetheless they focus both on entrepreneurship and on cost effectiveness and economic feasibility;
- k) Waste tariffs. The waste tariff charged on waste production funds the whole waste management system. It varies accordingly municipalities' strategies but, in average, it is charged about €250 for houses and €150 for apartments. Besides funding the treatment, it incentives recycling, once waste as to recycling is not charged;
- l) Integration of recycling and energy recovery. Currently the perspective that all kind of waste can be recycled is very distant. Even the recycling facilities produces waste which recycling is not feasible. This is the overriding point of view among the experts interviewed. Although all agree that the way towards the superior steps of waste hierarchy is the best solution, most of them highlights the importance of energy recovery to overcome the landfilling paradigm;
- m) The collaborative effort that congregates private companies, State institutions and the Academy. One common expression to appreciate projects or processes is the "Triple Helix", which represents this collaborative effort;

- n) Holistic approach when it comes to public policy. The decision makers always considers global factors. Consequently, great part of the environmental policy is covered by others institutions than the Environmental Ministry.

Based on all these features, Sweden developed a significant waste-to-energy industry which harness the energy content of waste and offset the fossil fuel use in heating and electricity, helping the country in decarbonizing its economy, as it is shown at Figure 3:

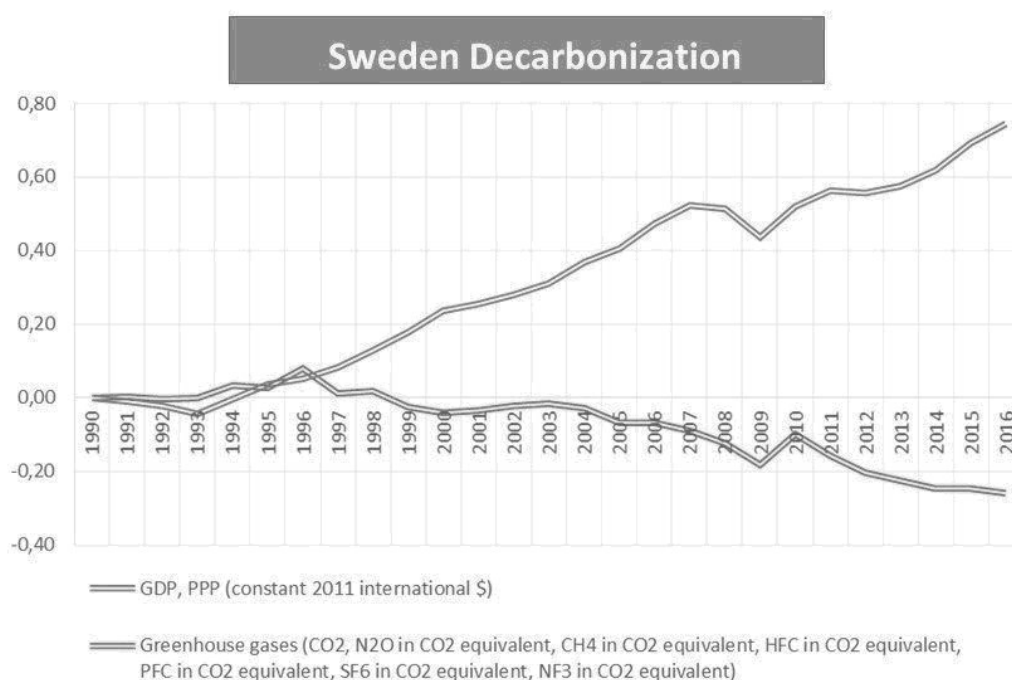


Figure 3 – Sweden Decarbonization (Source: Eurostat, 2018, and Word Bank, 2018).

Along the 1990-2016 period, Sweden has grown its GDP by 75%, while its CO₂ emission dropped by 26%. Among others initiatives as increasing biofuel use in transport sector, the use of waste to produce energy had a major role in its decarbonisation. Therefore, the listed factors were significant also to reduce the Sweden's climate impact.

4 Conclusions

Sweden has achieved one excellence level concerning its waste management when compared to most of countries. Less than 1 percent of its waste is landfilled, the worse option of the waste management hierarchy. Roughly half of the whole waste produced by its inhabitants produces directly energy through incineration, the remainder fraction is recycled. Additionally, the country helps other countries treating their waste, bringing fuel and economic resources to its economy. As well, the country reduced considerably its reliance on imported oil and its emission. The key factors of such achievement were listed above. But the main strategies comprise: (a) holistic policy approach regarding diverse public demands; (b) integration of recycling and energy recovery from waste; and (c) the use of economic instruments such as taxes and tariffs in order to discourage harmful and incentive positive practices and (d) municipality's autonomy with economic and operational capacity

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