Barriers to investment in energy saving technologies

Case study for the energy intensive chemical industry in the Netherlands

MSc Thesis Report

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Tabaré Arroyo Currás

For an environmentally aware and socially responsible leading, committed and accountable career.

Utrecht, 2010

Para mi hermano Cuitláhuac

Abstract

The Dutch government intends to realize ambitious climate targets by 2020. On account of this objective, attention has been given to the role of the chemical industry to become more energy efficient. This report assesses potentials and main obstacles to increase current process energy efficiency in the energy intensive chemical sector.

The overall results from a techno-economic analysis showed that more than 20 PJ of final energy can be saved by retrofitting, upgrading process control, and increasing heat recovery in energy intensive chemical processes. Capturing this potential would save over €250 million per year in energy costs and would reduce annual CO_2 emissions by more than 1 million tonnes.

Despite of their benefits, investment in energy saving measures is still limited, explained by the existence of barriers to investment in energy efficiency. Based upon the results of a survey and interviews covering firm representatives of the chemical industry and energy specialists from research institutes and consulting firms, this study also found that no single barrier can be identified as the main cause limiting investments in energy efficiency. However, under business as usual conditions, changes in energy prices, budget restrictions and other investment priorities,

technology fitting in actual processes, and lack of commitment are major barriers influencing energy saving investment decision making.

The general conclusion of this research was that cost effective energy efficiency improvement can be realized in the energy intensive Dutch chemical industry if barriers to investment in energy savings are overcome.

I. Introduction

Within the context of European endeavors towards climate change mitigation, the Dutch government intends to realize ambitious climate targets by 2020 e.g. achieving a 2% p.a. energy efficiency improvement in the coming years (VROM 2010)[1]. On account of this objective, attention has been given to the role of the industrial sector to reduce its energy use, and greenhouse gases emissions; for instance, the possibilities of the Dutch chemical industry (IChem-NL) to become cleaner and more energy efficient.

In the Netherlands, the manufacturing industry is the largest user of primary energy (Van Dril, A. W. N., Elzenga 2005) with a 40% share of the total primary energy consumption of the country[2]. The IChem-NL consumes more than 800 PJ per year[3] (Daniëls, van der Maas 2009) from which a large share is related to manufacturing of a few energy intensive products (Roes, Saygin & Patel 2010). Given the magnitude of the energy consumption in this sector, and in the context of realizing future energy saving targets, possibilities for further energy efficiency improvement have gained major attention by the Dutch government (VROM 2010, IEA 2009).

[1] Other targets are: to cut emissions of greenhouse gases by 30% in 2020 compared to 1990 levels, and to reach a share of renewable energy of 20% by 2020 (VROM 2010).
[2] Excluding the refinery sector.
[3] Primary energy in 2006; including non-energetic use.

According to different authors (Blok, de Visser 2005, Phylipsen et al. 2002, Nieuwlaar 2001, Nieuwlaar 2001), there is significant potential for energy savings in the IChem-NL by increasing energy efficiency - even at low costs (Martin et al. 2000a). However, despite the compelling economics of many energy saving measures, the sector has not been able to capture all of the opportunities available to it. Indeed, different studies suggest that such "*energy efficiency gap*"[4] can be explained by the existence of barriers to investment in energy saving opportunities (Rohdin, Thollander & Solding 2007). Therefore, as a prerequisite to achieve a higher energy-efficiency the obstacles must be overcome.

1.1 Problem definition and aims

Numerous studies have identified a wide variety of barriers to industrial energy efficiency improvements (Phylipsen et al. 2002, Rohdin, Thollander & Solding 2007, Mikunda 2009, Masselink 2008, Schleich 2007, Sorrell et al. 2004, De Groot, H. L. F., Verhoef & Nijkamp 2001, De Almeida, E. L. F. 1998, de Canio 1998, Velthuijsen 1993, Dyer et al. 2008)[5]. These barriers vary depending on general sector and regional circumstances (Sorrell et al. 1999), implying the need for more specific

[4] Jaffe and Stavins (Jaffe, Stavins 1994a) define energy efficiency gap as the gap that "*exists between current or expected future energy use, on the one hand, and optimal current or future energy use, on the other hand*".
[5] In addition, there are also many relevant studies that addressed the same theme but over different sectors (Velthuijsen 1993, Sorrell et al. 1999, Schleich, Gruber 2008, Scott 1997, Brechling, Smith 1994).

studies in order to identify effective energy policies at different levels (e.g. sub-sector and country specific) (Ramirez, Patel & Blok 2005).

With the aim of contributing to further understanding the potential energy efficiency improvement in the Netherlands, the present report addresses impediments to investments in energy-saving technology within firms of the IChem-NL. The overall objective of this study is to present a country and sub-sector specific analysis of broad potentials and main obstacles to increase current process energy efficiency in the chemical sector. In view of this, this assessment focuses in the energy intensive IChem-NL. This research was conducted partly at the Department of Innovation and Environmental Sciences of Utrecht University and partly at the National Energy and Emission Strategy Group of the Energy research Centre of the Netherlands.

1.2 Research questions and scope

The main focus of this research is to answer the following questions:

1) What sort of energy saving measures and technologies can be applied in the energy intensive IChem-NL to improve its energy efficiency?
2) What are the main barriers to investment in energy savings preventing such improvement from being realized in the sector?

Given the large spectrum of chemicals manufactured in the Netherlands, the scope of the project was limited to producers of ethylene, chlorine and polyethylene (PE) viz. LDPE & HDPE; the selection was justified by the fact that such products are among the top 10 most energy intensive chemicals produced in the Netherlands[6] (Roes, Saygin & Patel 2010).

1.3 General methodology

In this research, the methodology followed was based on a case study approach. For instance, by surveying and interviewing representatives of the different sub-sectors, and energy specialists from research institutes and consulting firms in the Netherlands[7]. In total, 17 participants (13 firm representatives and 4 energy specialists) were surveyed. The survey helped gathering information about: 1) energy performance in companies (e.g. energy system and energy saving opportunities at process level); 2) investment decision making (e.g. investments on energy savings and barriers to investment in energy efficiency); and, 3) policies for energy and climate (e.g. acceptability of policy instruments). At the end of the project, the response rate was favorable with a total of 11 respondents (65%). Besides, 13 out of the 17 participants (9 firm representatives and

[6] In this report, energy intensive IChem-NL refers to those producers of ethylene, chlorine and PE. Other energy intensive chemicals –not considered in this report- include: ammonia, propylene oxide, styrene, phosphorous and phosphoric acid.

[7] A minor part of the case study was conducted in Belgium in order to compare insights from competitors of those firms operating in the Netherlands (e.g. chlorine and PE producers). However, given the structural similarities of the industry within the BENELUX, such should not diminish representativeness of the outcome of this research.

4 energy specialists) were also interviewed in order to gain further understanding of the information shared in the surveys; these, accounted for more than 18hrs of recorded conversations.

To start with, a list of energy saving opportunities was synthesized using existing literature (Nieuwlaar 2001, Nieuwlaar 2001, Martin et al. 2000a, Creative Energy 2008, IPPC 2007, IPPC 2003, IPPC 2001). Next, by applying the surveys and conducting interviews, screening was performed to develop a list of measures and technologies with possible immediate or short term implementation; then the set of options were evaluated techno-economically (Chapter III).

Subsequently, regarding investment decision making and also based on relevant literature (Phylipsen et al. 2002, Rohdin, Thollander & Solding 2007, Mikunda 2009, Masselink 2008, Schleich 2007, Sorrell et al. 2004, De Groot, H. L. F., Verhoef & Nijkamp 2001, De Almeida, E. L. F. 1998, de Canio 1998, Velthuijsen 1993, Dyer et al. 2008), a selection of general barriers to investment in energy savings in the chemical industry was elaborated. For this purpose, exclusively those barriers that are attributed to economic or behavioral failures were considered (Sorrell et al. 1999)[8]; that is, barriers originated by organizational failures were not taken into account in this study. Then after, the selection was included in the surveys for review, and discussed during interviews. Later, the barriers were explained and qualified on the basis of its influence on energy-efficiency investment decision making (Chapter IV).

[8] The distinction is important, since only economic and behavioral failures may legitimate public policy intervention (Sorrell et al. 1999).

1.4 Differences with similar studies

Importantly, there are some aspects that differentiate this research from others similar to its kind:

1) The study focused on sector level, with specific attention to particular process at sub-sector level within the IChem-NL;
2) The study focused on final energy[9] to help understanding non energy specialists (e.g. business leaders and policymakers) about the magnitude of benefits that can be achieved by investing in energy efficiency;
3) The project only accounted for energy saving measures and technologies that are already in the market and have been applied successfully in the industry at large production scale; and finally,
4) The selection of relevant barriers was limited to the *business as usual* kind of investment decision making as commonly performed by corporate directors and energy managers in industry. Then, an exhaustive analysis of all possibilities was avoided.

[9] In this report final energy use refers to the type of energy that is the product of an energy conversion process e.g. electricity or heat. In other words, final energy use or consumption will exclusively refer to secondary energy use (Blok 2007).

1.5 Outline

This report presents the findings of the work in the following 4 chapters:

I. The IChem-NL: an overview;
II. Improving energy efficiency in the energy intensive IChem-NL: energy saving opportunities at process level;
III. Investment decision making in the energy intensive IChem-NL: barriers to investment in energy saving technology; and,
IV. Industrial energy efficiency look ahead: conclusions.

II. The IChem-NL: an overview

The Netherlands holds an outstanding climate for the development of the chemical industry. Given its favorable geographical location, important raw materials are available or can be easily supplied. Besides, in conjunction with an extensive transportation network (including waterways and pipelines), the IChem-NL has excellent access to European markets. On the whole, all these preconditions, contribute creating a leading and influential chemical industry that constitutes a driving force for the Dutch economy.

In the Netherlands, the chemical industry is one of the highest energy consumers of the country. In fact, the IChem-NL is responsible for 67% of the industrial energy use[10] (Daniëls, Kruitwagen 2010), and 50% of the CO_2 –direct- emissions of the manufacturing sector (Statline 2010a) [Figures 2.1 and 2.2]. Surprisingly, this amount of energy and emissions (838 PJ in 2008[11]), is mostly originated by processing a small number of energy intensive chemical compounds, of which few organics, inorganics, fertilizers, and plastics in primary forms are the most important. As follows, in this chapter a short review of the IChem-NL and its energy performance is presented.

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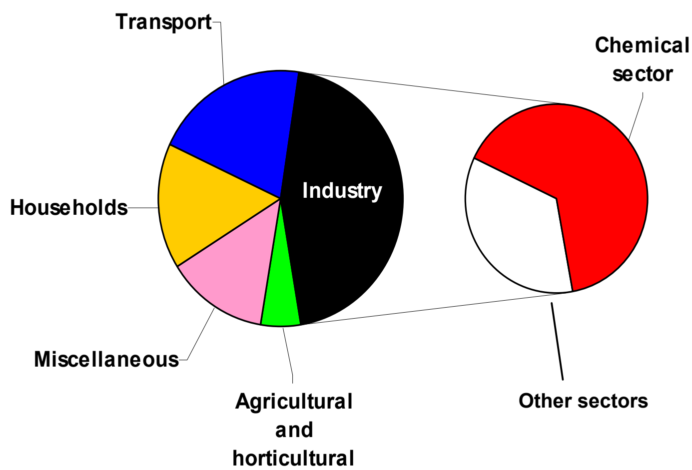
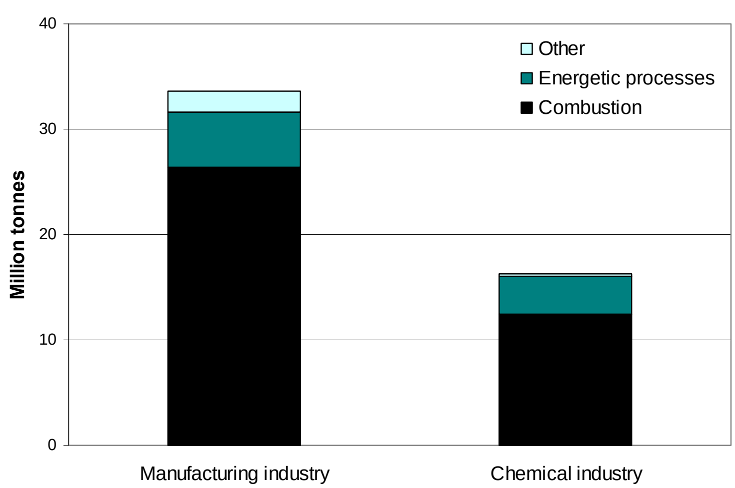
[10] About 25% of the energy use in the country.
[11] Final energy use, including non energetic use.

Figure 2.1. Shares of final energy in the Netherlands in 2006



Based on (Daniëls, van der Maas 2009). Including non-energy use.

Figure 2.2. Direct CO2 emissions of the Dutch manufacturing sector and chemical industry in 2007



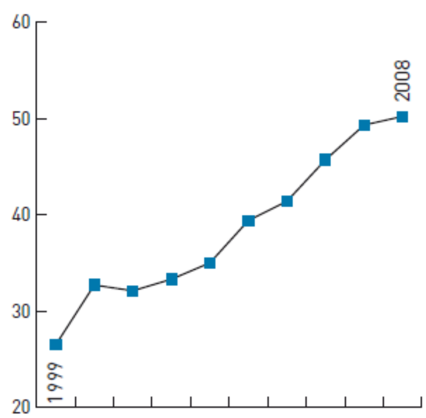
Based on (Statline 2010a)

2.1 Sector economics

The chemical sector plays a fundamental role in the economy of the Netherlands. For instance, the IChem-NL ranks second in the world, after Belgium, in terms of relative contribution of a country's chemical industry to GDP (Young 2003): 10%[12] (VNCI N.D.). In 2008, the chemical sector employed more than 66,000 employees and generated a turnover of 50 billion euros a year (a 2% increase over 2007) (VNCI 2008)[13]. Besides, with a (gross) value added of €14 billion euros in 2008, the sector accounted for 3% of the Dutch GDP (i.d.) [Figure 2.3]. Also, the sector accounts for 17% of national exports, and 25% of the total research and development (R&D) spending in the Dutch industrial sector (i.d.)[14].

Figure 2.3. IChem-NL turnover history 1999-2008

(in billion Euros)



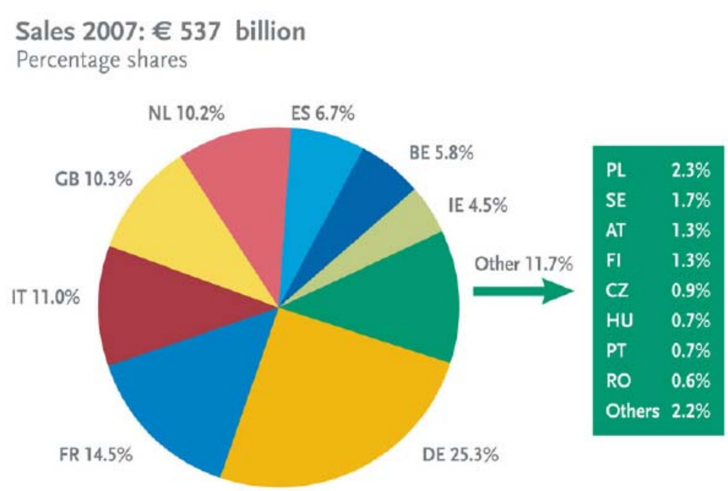
From (VNCI 2008).

[12] Indirect contribution to GDP.
[13] Nonetheless, according to VNCI (Gray-Block 2009) , economic crisis impacted on a 5% production fell and 25% sales fell, slipping back the economic performance of the IChem-NL to 2003 levels.
[14] According to the Netherlands Organisation for Applied Scientific Research (TNO), the Netherlands was ranked third amongst the top research countries, after United States and Switzerland. This position is due to a large extent to the contribution made by the chemical industry (VNCI N.D.).

2.2 European positioning

Based on sales, the IChem-NL was the 5th biggest chemical industry in the European Union (EU) in 2007, accounting for about 10% (monetary terms) of EU's chemicals industry sales (CEFIC 2009) [Figure 2.4]. In view of its relatively small size and population[15], and the location there of the port of Rotterdam[16], the Netherlands export about 75% of its chemicals output, of which 75% goes to countries in Europe, and 25% is exported overseas (VNCI 2008). According to VNCI, exports in 2008 amounted € 62 billion.

Figure 2.4. Geographical breakdown of EU chemical industry sales

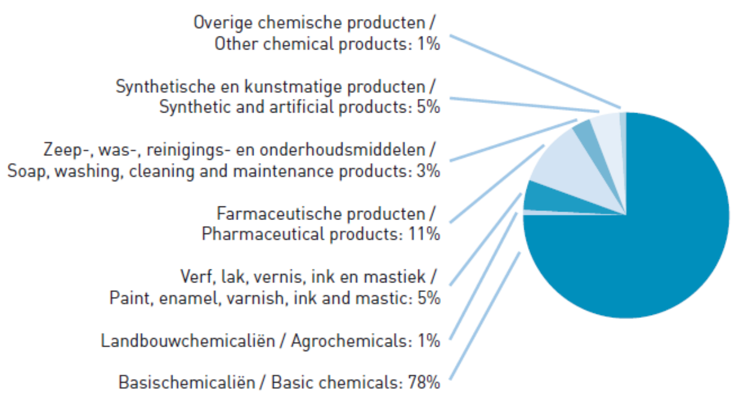


Big 8= Germany (DE), France (FR), Italy (IT), United Kingdom (GB), Netherlands (NL), Spain (ES), Belgium (BE) and Ireland (IE). From CEFIC (2009).

[15] Population density in the Netherlands is 489 capita/km^2 (Statline 2010b).
[16] With throughput of more than 421 million tonnes of goods, Rotterdam is by far the largest seaport in Europe (Port of Rotterdam Authorithy 2009).

The Netherlands is established as a major producer of chemical commodities (viz. bulk chemicals), particularly petrochemicals (Young 2003). Bulk chemicals account for about 78% of the country's chemicals sales and specialties make up the rest (e.g. food ingredients, coatings and high-performance materials) (VNCI 2008) [Figure 2.5].

Figure 2.5. Shares of chemical sales in the IChem-NL



From VNCI (2008).

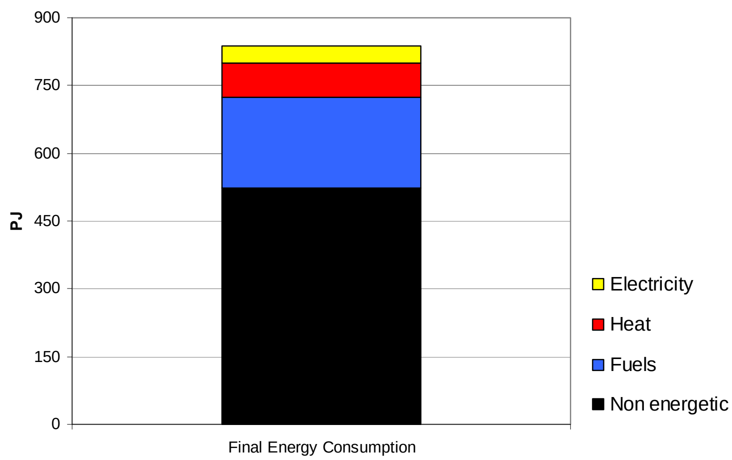
2.3 Energy consumption

The chemical industry in the Netherlands, consumes coal, oil products, natural gas, electricity and heat, using them both as raw materials (feedstock) and as power and fuel (CEFIC 2009). In 2008 the sector used more than 800 PJ of final energy[17] (Daniëls, Kruitwagen 2010) [Figure 2.6], contributing to more than 50% of the total CO_2 emissions of the whole industrial sector (over 16 million tonnes of CO_2 per year (ECN

[17] Including non-energetic use.

2009)). Feedstock accounted for almost 58%, while fuels and power for the remaining 42%, taking all sources of energy into account (i.e. fuels, 28%; electricity, 5%; and, heat, 9%). Thus, on the whole, the chemical sector accounted for around 65% of the total final energy use in the Dutch industry[18].

Figure 2.6. Final energy consumption in the IChem-NL in 2006, by source



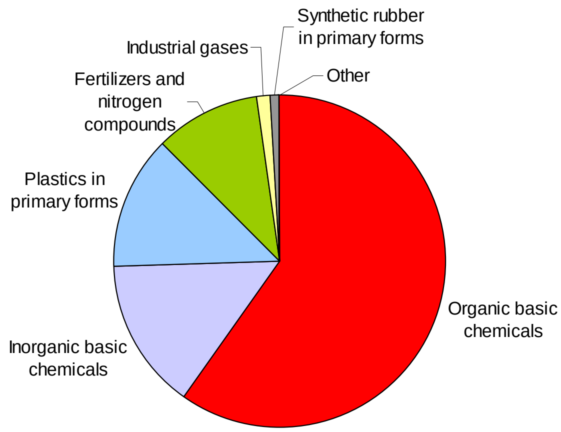
Based on (Daniëls, Kruitwagen 2010).

At the sector level, a large share of the total primary energy use is related to manufacturing of few energy intensive chemicals such as organics (e.g. ethylene, propylene oxide, and styrene), inorganics (e.g. chlorine), fertilizers (e.g. ammonia), and plastics (e.g. PE, polystyrene; and polypropylene). Around 60% of the final energy use of the sector can be attributed to the production of organic basic chemicals; other relevant

[18] Final energy use in the industry was 1188 PJ (Daniëls, van der Maas 2009); including non-energetic use.

contributors are inorganic basic chemicals (15%), and plastics in primary forms (13%) (Roes, Saygin & Patel 2010) [Figure 2.7].

Figure 2.7. Primary energy use share of the chemical industry in 2005



Based on (Roes, Saygin & Patel 2010)

2.4 Organic basic chemicals: ethylene

Ethylene ranks first among energy consuming organic chemicals in the Netherlands, with about 3.4 million tonnes produced per year[19]. It is a principal building block for the petrochemicals industry (and the lower olefin sub sector), with almost all of the ethylene produced being used as a feedstock for manufacturing plastics (e.g. PE; polystyrene, PS; vinyl acetate; polyvinyl chloride, PVC; etc.) and other organic chemicals (e.g. ethylene oxide, glycol, etc.) that are ultimately consumed in the packaging, transportation and construction industries and multiple industrial and consumer markets.

[19] Estimation based on total capacity of 4 million tonnes per year in the Netherlands (Koottungal 2009), at a 85% operation rate.

2.4.1 Production capacity in the Netherlands

The full nameplate production capacity in the Netherlands is close to 4 million tonnes per year (Koottungal 2009), and accounts for some 17% of Western Europe total production capacity[20]. Dutch ethylene production capacity has expanded by 1 million tonnes in the last 10 years[21], but this increase has been achieved only through the expansion and optimization of existing plants. Within the Netherlands there are 3 crackers and these are allocated in 3 different sites [Table 2.1].

In the Netherlands, liquid naphtha (from crude oil refining) is by far the most important raw material and accounts for 93% of ethylene production (i.d.). Propane, less significantly, is also used to produce ethylene. As in the rest of Europe, liquid feeds predominate because they are relatively abundant and easy to transport.

Operator	Location	Capacity (ktonne/year)	Type of Feedstock
Shell	Moerdijk	900	100% Naphtha
SABIC	Geleen	1265	100% Naphtha
Dow Chemicals	Terneuzen	1800	15% Propane/ 85% Naphtha

Table 2.1. Production capacity of ethylene in the Netherlands.

Based on (Koottungal 2009)

[20] Total capacity in Western Europe (2004) was 24 million tonnes per year (IEA 2007b).
[21] Total ethylene capacity in the Netherlands in 1999 was 3 million tonnes per year (Radler 1999).

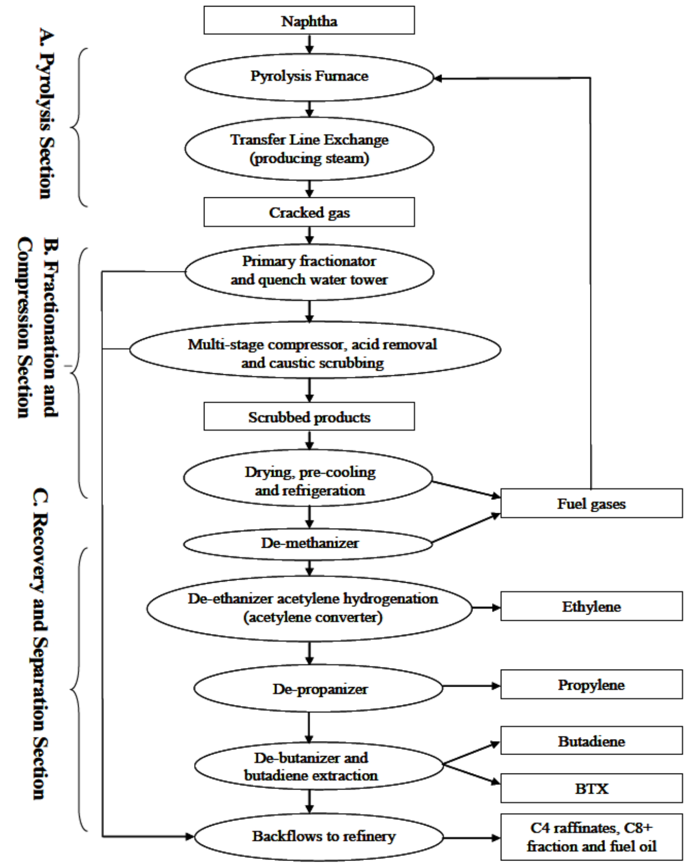
2.4.2 Applied process

In the Netherlands, almost the entire demand for ethylene is produced using naphtha steam cracking process[22]. In this process, suitable hydrocarbons are heated to elevated temperatures (750-875 ºC), in the presence of steam, to separate the original feedstock into lower olefins products (IPPC 2003). Ethylene production technology is licensed by generic designs utilized by few contractors, but with modifications that optimize plant performance to local conditions (e.g. integrated energy efficiency[23]). Variations might include particular technologies (e.g. equipment such as furnaces, heat exchangers, refrigeration systems) or specific operation conditions (e.g. temperature or pressure). Regardless of the process technology applied, ethylene production generically includes these common components (IEA 2007b):

- Pyrolysis section in which feedstocks are cracked in the presence of steam;
- Primary fractionation and quench system in which heavy hydrocarbons and water are removed;
- Compression section, acid removal and caustic scrubbing; and,
- Fractionation section at both cryogenic and moderate temperatures in which the various products are separated and purified [Figure 2.8].

[22] Dow Chemicals Plant in Terneuzen processes 15% propane as feedstock.
[23] In this case, integrated energy efficiency refers to the adequate matching of energy sources (e.g. hot streams) and energy sinks (e.g. cold streams) to improve energy use (e.g. heat transfer).

Figure 2.8. Typical flow chart for a naphtha steam cracker



From (Ren 2009a)

2.4.3 Energy consumption

The steam cracking of naphtha is a highly endothermic process, and requires large quantities of energy at high temperature (>800°C) to achieve hydrocarbon dissociation as well as for cryogenic separation processes (temperatures as low as -150°C) to separate and purify products (IPPC 2003). Although energy performance in crackers depends on feedstocks effects, site energy integration, size and age of production units, current average final energy consumption levels in the Netherlands are about 28 GJ/ tonne ethylene (excluding feedstocks)[24], of which 98% are fuels and 2% are electricity (Saygin et al. 2009)[25].

2.5 Inorganic basic chemicals: chlorine

Chlorine is one of the most important products of the chemical industry in Europe. Among its applications, chlorine is used as feedstock in the production of relevant chemicals such as inorganics (e.g. disinfectants and water treatment); other organics (e.g. detergents and insecticides); PVC; isocyanates & oxygenates products (e.g. plastics and pesticides); solvents, chloromethanes and epichlorohydrin (Euro Chlor 2009).

2.5.1 Production capacity in the Netherlands

In the Netherlands the chlorine industry accounts for a total production capacity of about 830,000 tonnes per year. In 2008, European production was in the order of 11 million tonnes of product (Euro Chlor 2009), at an 85% of maximum capacity utilization. As a result, the Netherlands is positioned in Europe as one of the top three largest chlorine producers (around 7% of the total European production)[26]. In the Netherlands, Chlorine is produced at three sites [Table 2.2].

[24] Solomon Associates Inc. have benchmarked 115 olefin plants, representing 70% of the ethylene-producing capacity worldwide (IEA 2007b). According to them (sic.), steam crackers in the Netherlands are ranked among the top quartile of most efficient steam crackers in the world.
[25] Steam is produced internally and is in balance.
[26] According to Eurochlor (2009), Belgium and the Netherlands –together- account for 14% of the chlorine output of the European market. Total manufacturing in Belgium in 2007 was about 892 ktonnes of product, at 85% of maximum capacity utilization (i.d.). Germany remains as the largest chlorine producer in Europe with 43% of European production.

Operator	Location	Capacity (ktonne/year)	Type of Process
Akzo Nobel	Botlek	633	Membrane
	Delfzjil	109	
SABIC	Bergen-op-Zoom	89	

Table 2.2. Production capacity of chlorine in the Netherlands.

Based on (Euro Chlor 2009)

2.5.2 Applied process

In the Netherlands chlorine is produced exclusively by electrolysis using the membrane process [Figure 2.9] [27]. Specifically in this process, an anode and a cathode are divided by a water-impermeable, ion-conducting membrane (Schmittinger 2000). In here, a brine solution flows through the anode compartment where chlorine gas is generated. Then, sodium ions travel through the membrane to the cathode compartment, where sodium hydroxides solution is flowing (i.d.). Finally, water hydrolyzes at the cathode and releases hydrogen gas and hydroxide ions; these, in combination produce sodium hydroxide[28] (Energetics 2000). In general terms, the development of this technology over others has obeyed advantages such as its relatively pure caustic solution production at lower energy requirements, and its avoidance to use toxic materials (e.g. asbestos, mercury).

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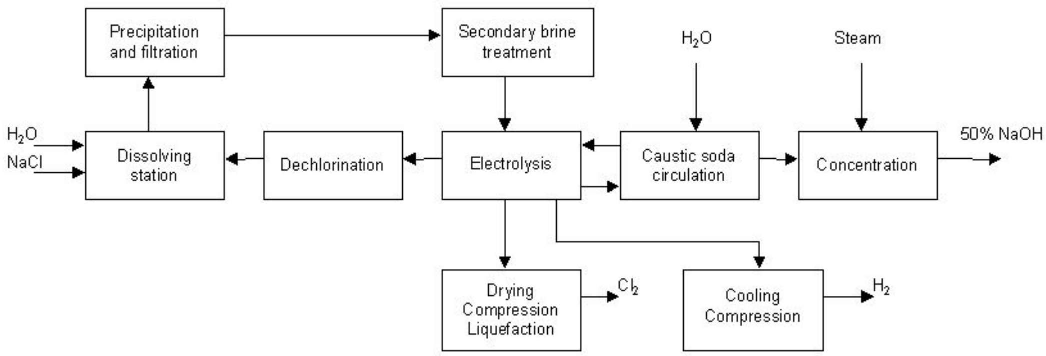
[27] Other process used in Europe are the mercury process and the diaphragm process.
[28] The membrane process produces a 30% sodium hydroxide product (IEA 2007b).

Figure 2.9. Typical flow chart for a membrane process



From (IPPC 2001)

2.5.3 Energy consumption

In the cell process, energy is used as electricity and heat (e.g. steam for brine preparation and NaOH concentration). However, electricity is the primary source of energy of the electrolysis process (it accounts for 84% of the total energetic requirement (sic.)). The quantity of electricity needed depends upon the design of the cell and operating current, as well as the concentration of electrolytes, temperature and pressure. In the Netherlands, average energy intensities of this process are around 12 GJ/tonne of chlorine (IPPC 2001)[29].

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[29] Energy value covers the electrolysis of sodium chloride as a whole, i.e. including the concentration of sodium hydroxide to 50%; the steam consumed for brine preparation and sodium hydroxide (NaOH) concentration; power requirements for rectifiers; and, power requirements for cooling NaOH, and hydrogen cooling and drying. It is excluded: liquefaction/evaporation of chlorine and its gas compression, and credits for by-product hydrogen (Saygin et al. 2009).

2.6 Plastics in primary forms: PE

PE is the most produced polymer worldwide (IPPC 2007). PE, due to its intrinsic properties (e.g. strength and vast applicability), is found in everyday objects such as packaging, pipes and toys. Depending on the physico-chemical properties of the end use application, different types of PE can be distinguished. For instance, among the most commercialized kinds of PE, there is the low density PE (LDPE) and the high density PE (HDPE). Whereas LDPE (a soft, tough and flexible kind of PE) is produced in a high pressure process[30], HDPE (a more rigid and less bendable kind of PE)[31] is produced at low pressure.

2.6.1 Production capacity in the Netherlands

In the Netherlands, production capacity of PE includes 855,000 tonnes LDPE (CW research 2005), and, 920,000 tonnes HDPE per year (SRI Consulting 2006)[32]. This represents 14% of the total LDPE capacity and 10% of the total HDPE capacity in Western Europe (i.d.). PE in the Netherlands is produced at two sites [Table 2.3].

[30] Typical density of LDPE lies between 915 and 935 kg/m^3 (IPPC 2007).
[31] Typical density of HDPE is higher than 940 kg/m^3 (i.d.).
[32] Linear low density PE (LLDP) is also produced in the Netherlands.

Operator	Location	Type	Capacity (ktonne/year)
SABIC	Geleen	LDPE	590
		HDPE	280
Dow	Terneuzen	LDPE	265
		HDPE	640

Table 2.3. Production capacity of PE in the Netherlands.

Based on (CW research 2005, SRI Consulting 2006) LLDP is not included.

2.6.2 Applied process

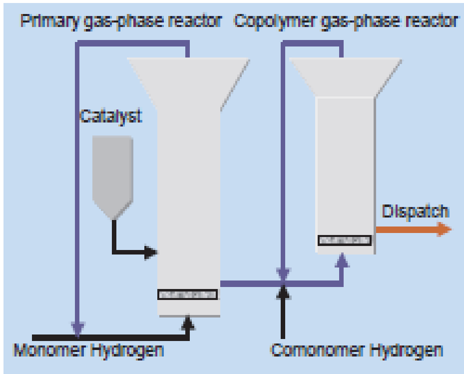
PE is made in a polymerization reaction by building long molecular chains comprised of ethylene monomers by using catalysts (Siemens AG 2007)[33]. A wide variety of production processes exist for PE with some general similarities [Figure 2.10]. For instance (i.d.):

- Feedstocks materials and additives are purified and catalysts are added;
- Polymerization takes place either in gas phase (fluidized bed or stirred reactor), liquid phase (slurry or solution), or in high pressure environment;
- Polymer particles are then separated from still existing monomers and diluents, palletized, dried and dispatched; and,

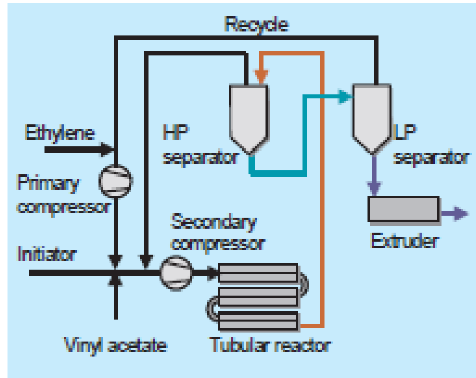
Monomers and diluents are recovered and recycled into the process.

[33] The type and nature of the catalysts have a great impact in the polymerization process. Some of the most widely used are: Ziegler-Natta ($TiCl_3$), Chromium (Cr_2O_3), Metallocene (e.g. Zr, Ti), or late-transition metals (e.g. Pd, Ni, Fe) (McKenna 2008).

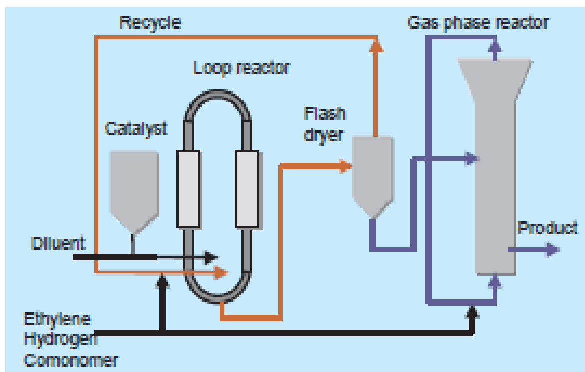
Figure 2.10. PE production principles



a) Gas phase



b) High-pressure



c) Liquid-phase

From (Siemens AG 2007)

2.6.3 Energy consumption

Energy consumption in PE production varies depending on the molecular weight distribution of the PE resin to be produced, heat transfer, and performance of the initiation system (IPPC 2007). Nonetheless, based on best practice technology, final energy consumption are in the order of 3 GJ/tonne and 2 GJ/tonne for LDPE[34] and HDPE respectively (i.d.). Given that in the Netherlands PE production ranks top

[34] Surplus of low pressure steam is not considered – 2.1 GJ/tonne LDPE - (Saygin et al. 2009).

regarding energy consumption, same values can be considered as representative (sic.).

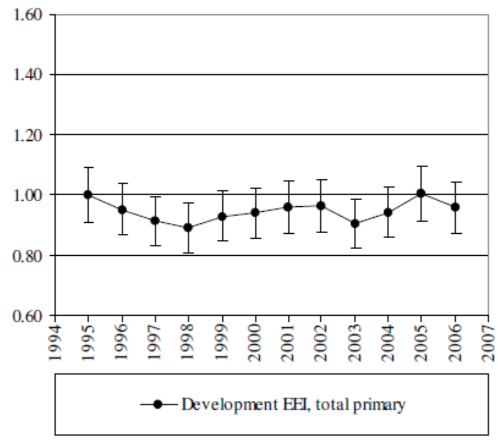
2.7 Energy efficiency

According to some studies (Roes, Saygin & Patel 2010, Saygin et al. 2009, Neelis, Ramirez & Patel 2004, Roes, Neelis & Ramirez 2007, Roes, Patel 2008), it is still uncertain if the IChem-NL has succeeded in increasing its energy efficiency over the last decades. In particular, studies have shown that the chemical sector has been inconsistent in reducing its energy consumption in comparison with other sectors. For instance, Roes and Patel (2008), through calculating energy efficiency developments in the Dutch manufacturing industry using physical indicators of production[35], estimated that the development of the energy efficiency fluctuated between 1995 and 2006. Based on total primary energy use[36], the chemical sector[37] became more energy efficient from 1995 to 1998 whereas less energy efficient from 1998 to 2002 [Figure 2.11]. Indeed, although their report showed that the chemical industry became more efficient with respect to consumption of electricity, heat and fuels, the effect on the overall energy efficiency improvement was small as a result of the grow in non-energy use . Then, the analysis indicates that energy savings in the sector are smaller than in other energy intensive industries (e.g. iron and steel basic metals, pulp and paper,

[35] The full methodology is described in a report by Neelis et al. (Neelis, Ramirez & Patel 2004).
[36] Non energetic use+fuels/heat+electricity.
[37] Excluding the fertiliser industry.

building and materials, and non-ferro basic metals industries), which can be attributed to the high share of feedstocks (non-energy use). Nonetheless, as the authors suggest, such straight comparison among sectors is hard to verify given the high uncertainty behind energy data. Then, a more meaningful comparison would be one made at process level e.g. comparing process energy with process energy.

Figure 2.11. Development of energy efficiency indicator for total primary energy use (static primary units) in the Dutch chemical industry.



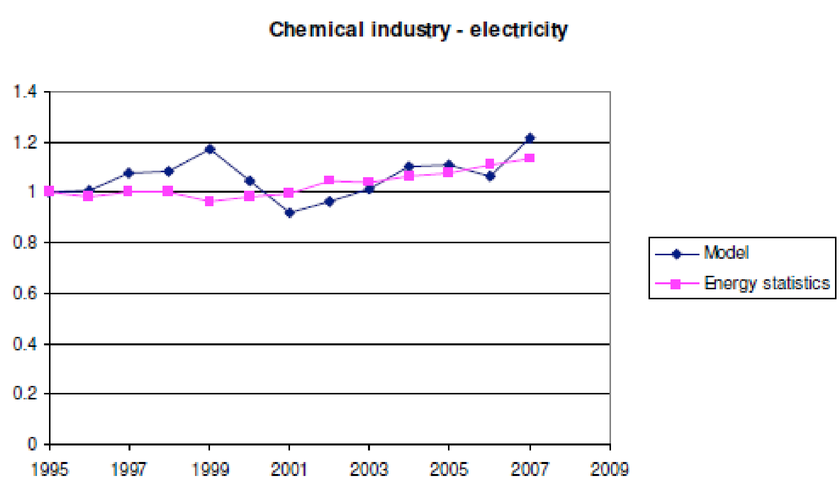
From Roes and Patel (2008)

Similarly to the previous study, Roes et al (2010) determined energy efficiency improvement by comparing real measured energy use of the IChem-NL (as reported by statistics) with a reference energy use for the years 1995-2007[38] (viz. indexing energy use). In this case, the conclusion reached was that the IChem-NL gained practically no energy efficiency improvement during that period. For example, the study showed that

[38] The methodology followed was based on a 'bottom-up' approach, were a 'frozen' efficiency is assumed that can serve as benchmark to estimate real energy efficiency improvements if energy statistics are compared to it. The full methodology is explained in detail in the report (Roes, Saygin & Patel 2010).

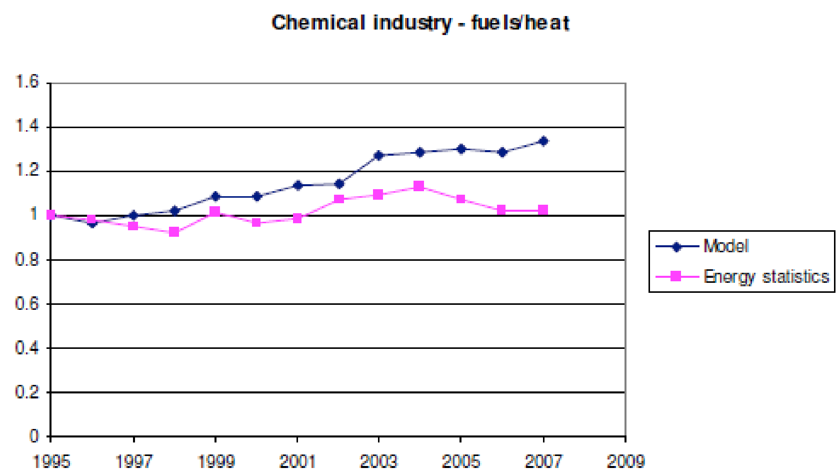
efficient electricity consumption started decreasing from 2001 [Figure 2.12a]. Besides, regarding fuels and heat, the same effect was perceived until 2003 (then after, some increase in efficiency was achieved) [Figure 2.12b]. Finally, efficiency in non-energy use also started decreasing since 1998 [Figure 2.12c]. Overall, taking into account total primary energy use, it seems that the efficiency improvement in the sector has decreased substantially in the last decade; at sub sector level, similar outcomes where found for the production of organics, inorganics and basic chemicals (e.g. plastics in primary forms). It should be noted that, the results presented in this study are also subject to uncertainty, especially regarding the technical production of products included in the energy modeling (viz. process specific energy consumption values and production amounts).

Figures 2.12. Indexed energy use of the Dutch chemical industry modeled by Roes et al (2010) (continues).

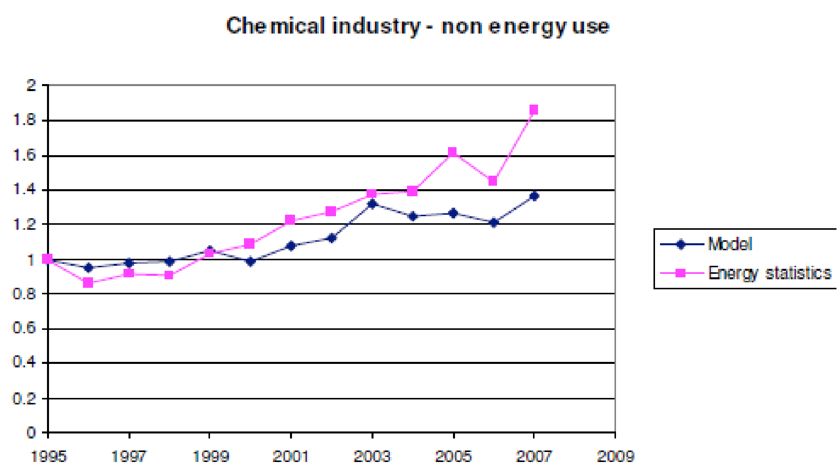


a)

Figures 2.12. Indexed energy use of the Dutch chemical industry modeled by Roes et al (2010)



b)



c)

In contrast to the previous studies, Saygin et al. (2009) estimated potential for energy savings and CO_2 emissions reductions by Best Practice Technology (BPT) in chemical processes for different countries. In their report, it was concluded that, for the Benelux, the estimated BPT energy use exceeds the total final energy use reported in energy statistics, i.e. energy efficiency improvement potentials are negative. This would imply that, in the region, existing processes can be more efficient than BPT. Nonetheless, given that (i) only best practice in the European chemical and petrochemical sector was considered (worldwide BPT was not available), (ii) heat cascading[39], and (iii) energy efficiency improvements related to combined heat and power were not accounted; real improvement potential could be larger.

From the previous studies, it is not clear whether the IChem-NL has succeeded in increasing its energy efficiency or not. Whatever the case, different authors affirm that there are still many opportunities for this to happen. In the next chapter, a review of opportunities for improving energy efficiency in the sector will be performed. After that, a description of the most influential barriers to investment in such opportunities will be presented.

[39] By heat cascading it is meant the reusability of high-pressure steam as medium-pressure steam and subsequently also as low-pressure steam.

III. Improving energy efficiency in the energy intensive IChem-NL: energy saving opportunities at process level

In this research, theoretical energy savings potential as well as net present value (NPV)[40] investment costs and benefits were identified for ethylene, chlorine and PE processes; this chapter presents the results. Firstly, the methodology for estimating such potentials is introduced. Then, the findings will be summarized for the different processes.

3.1 Methodology for estimating potential energy savings

To calculate energy savings at process level ($SAVE_i$) the approach followed was based on the analysis of *energy efficiency chains*. Then, estimations of process specific energy use (SEC_i)[41], shares of energy consumption by fuel type ($SHARE_{Fuel,f(i)}$), shares of energy consumption by process step ($SHARE_{Step,f(i,m)}$) and energy saving potentials by measure

[40] NPV-positive refers to: "*the present value of energy, operation, and maintenance savings that accrue over the lifetime of the measure and are equal or greater than the upfront investment to deploy that measure when discounted at an appropriate discount rate*" (Granade et al. 2009). For this purposes, 8% was used as discount rate.

[41] For simplicity, and in order to avoid confusion with other definitions, in this report SEC is limited to the value of energy consumed in a given process (in final terms) viz. electricity, fuel and heat.

(POT_m) were multiplied among each other simulating a cascade of energy consumption (Equation 3.1).

$$SAVE_i = \sum_{1}^{m} SEC_i \times SHARE_{Fuel,f(i)} \times SHARE_{Step,f(i,m)} \times POT_m \qquad (3.1)$$

To illustrate, for a given process (e.g. chlorine), it was first estimated what the SEC of such process in the Netherlands would be (e.g. 12 GJ/tonne). Second, the $SHARE_{Fuel}$ within the process was estimated (e.g. electricity 84%, heat 16%). Subsequently, depending on the process step in which the defined measure could be applied the $SHARE_{Step}$ was allocated (e.g. electrolysis 72%, NaOH concentration 15%, etc.). Finally, the previous values were combined and multiplied by the specific POT_m of the measure being calculated as expressed in Equation 3.2 (example). The values of SEC, $SHARE_{Fuel}$, and $SHARE_{Step}$, used in the different calculations, were based mainly on expert opinion of manufacturers of the processes being reviewed; such information was mainly gathered during the interviews with firm's representatives. On the other hand, POT_m values were obtained from different scientific literature sources.

$$SAVE_{ODC\ in\ Cl_2} = 12\frac{GJ}{tonne} \times 84\%_{Electricity} \times 72\%_{Electrolysis} \times 30\%_{ODC} \qquad (3.2)$$

In this way, energy savings per unit of product were anticipated at process level for all the measures and technologies considered in this report. Then, by multiplying the various $SAVE_i$ values by total production (in the Netherlands) of the specific chemical process and adding them all together, total energy savings in the process ($SAVE_T$) –at national level- were estimated. For this purpose, total production of chemicals was calculated by considering an 85% production rate, based on specific capacities as defined in tables 2.2, 2.3, and 2.4 (Chapter II). Although slight variations of the method were applied in some cases[42], the general procedure was consistent for most of the options analyzed. Tables 3.1 and 3.2 summarizes SEC, $SHARE_{Fuel}$, $SHARE_{Step}$ and POT values for the different processes and measures as used in the calculations; Appendix A includes the fact sheets of the different options considered in this report.

SEC (GJ/tonne)		**$SHARE_{Fuel}$**	
Ethylene	28.0	Heat	98%
		Electricity	2%
Chlorine	12.0	Electricity	84%
		Heat	16%
HDPE	2.1	Electricity	47%
		Heat	53%
LDPE	2.6	Electricity (without surplus heat)	100%

Table 3.1. SEC and $SHARE_{Fuel}$ inputs as used in this research.

Measure	**Measure Type**	**$SHARE_{Step}$ X POT (% unless stated)**
Heat recovery	Crosscutting	2-6%
Process control sensors		1-6%
Heat integrated distillation column (HIDiC)+Heat pump	Process specific	0.3-0,5 GJ/tonne
Gas turbines		3-4 GJ/tonne
Oxygen depolarized cathodes		25-30%
Static mixers LDPE		10-40%
Static mixers HDPE		10-60%

Table 3.2.Combined $SHARE_{Step}$ and POT inputs as used in this research.

[42] In some situations, POT values were found in literature being already expressed as process specific energy savings (e.g. GJ_{saved}/ tonne of product) rather than energy savings potential (e.g. % of energy savings).

3.2 Methodology for estimating cost of energy savings

In order to estimate cost of energy savings per measure (COE), firstly, the annualized cost (*A)* of the selected energy saving measure or technology was calculated. Such cost includes the annualized investment costs (I) plus the operation and maintenance costs (O&M) (Equation 3.3). Regarding investment costs, data found in literature was adjusted by time corrections (viz. inflation and currency exchange), and scaled up when required[43]. When data about O&M costs were not available in literature, it was assumed to be equal to 10% of the investment costs. To annualize the investment costs, a capital recovery factor (α) was applied based on an 8% discount rate and the specific technical lifetime (L) of the measure being evaluated (Equation 3.4). Finally, annualized costs were divided by a reference amount of energy saved ($SAVE_R$) (Equation 3.5). To estimate $SAVE_R$, $SAVE_i$ values were multiplied by reference production rates (tonnes/year) based on average capacities of current large scale chemical plants[44]. In Appendix B, investment costs, O&M costs for the different measures and further details of the economic assessment can be found.

$$A = I \cdot \alpha + O\,\&\,M \quad (3.3)$$

$$\alpha = \frac{8\%}{\left(1-\left(1+8\%\right)^{-L}\right)} \quad (3.4)$$

[43] In some occasions, data found did not represent investment costs applicable to current large scale capacities.
[44] For instance, in the case of ethylene, 500 ktonnes/year; chlorine, 400 ktonnes per year; LDPE, 300 ktonnes/year; and, HDPE, 320 ktonnes/year.

$$COE = \frac{(A)}{(SAVE_R)} \quad (3.5)$$

3.3 Methodology for estimating NPV costs and benefits

Based on $SAVE_T$ values, annual costs of savings (CS) and annual benefits of savings (BS) were also calculated. For instance, to estimate annual costs of savings, $SAVE_T$ values were multiplied by respective COE (Equation 3.6). On the other hand, to estimate annual benefits of savings, $SAVE_T$ (based on type of energy e.g. heat or electricity) were multiplied by its respective cost of energy (Equation 3.7). For this part assumptions made were: (1) Costs of electricity were considered as 0.0918 €/kWh_e (Europe's Energy Portal February 25th 2010)); (2) To estimate benefits from fuel and heat savings, it was considered the price of natural gas as reference. For the case of fuels, the cost of natural gas was used directly; for the case of heat, it was assumed as the cost of burning it in a boiler to produce steam (conversion efficiency 90%); and (3) costs of gas were considered as 0.0325 €/kWh_g (i.d.). Finally, NPV costs (NPV_C) and NPV benefits (NPV_B from 2010 to 2020 were calculated by dividing annualized costs or benefits with a capital recovery factor of 15%[45] (Equations 3.8 and 3.9)[46]. Appendix B includes further details about the outcomes derived in this step.

$$CS = COE \times SAVE_T \quad (3.6)$$

[45] The recovery factor assumed includes an 8% discount rate for a 10 year period.
[46] NPV costs include investment costs and O&M; as it can be further track it down to equation 3.3.

$$BS = Energy\ \ price \times SAVE_T \tag{3.7}$$

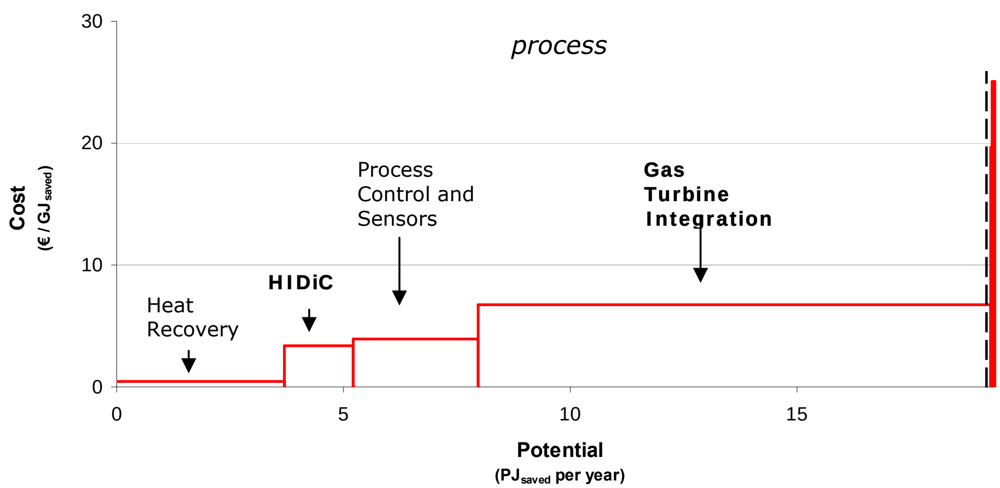
$$NPV\ \ costs = \frac{CS}{15\%} \tag{3.8}$$

$$NPV\ \ benefits_m = \frac{BS}{15\%} \tag{3.9}$$

3.4 Energy saving opportunities in ethylene production

Saving measures in the ethylene manufacturing industry in the Netherlands include current process improving by retrofitting, upgrading process control, and increasing heat recovery [Figure 3.1]. Interesting process specific retrofit options are heat integrated distillation columns (HIDiC) and gas turbine integration.

Figure 3.1. Ethylene energy abatement curve: measures and technologies, potential magnitudes, and incremental costs of options to reduce energy in process



3.4.1 Heat integrated distillation column (HIDiC)

Compared to conventional distillation columns, HIDiCs provide separation in sequences with considerable energy savings (0.1 to 0.3 GJ/t ethylene (Anonymous 2002, Vaartjes 2002). The main feature of this type of columns is its capability to reduce the number of necessary distillation columns during the separation section of the ethylene process without affecting the quality of final products (Kaibel 2009)[47]. Overall, HIDiCs improve heat transfer by allocating heat exchangers between the stripping and rectifying sections (they can be applied in the de-ethanizer and the de-propanizer) (Anonymous 2002, Vaartjes 2002). Besides, HIDiCs can be upgraded by using heat pumps (energy gain up to 0.15 GJ/tonne ethylene (Ren 2009a)). Therefore, HIDiCs possesses a very attractive characteristic that stimulates pursuing its application in the light olefins industry (Nakaiwa et al. 2003).

In the Netherlands, HIDiCs (upgraded with heat pumps) have a potential of around 2 PJ in final energy savings. This would represent a 2% energy efficiency improvement in the process at a COE in the range of 2.5 to 5 €/GJ_{saved} (close to 3.5 €/GJ_{saved} under BAU conditions) [Figure 3.2][48]; and payback time close to 2 years. On the whole, the implementation of this technology in the Netherlands would have NPV investment costs of €40 million with NPV benefits of about €90 million by 2020.

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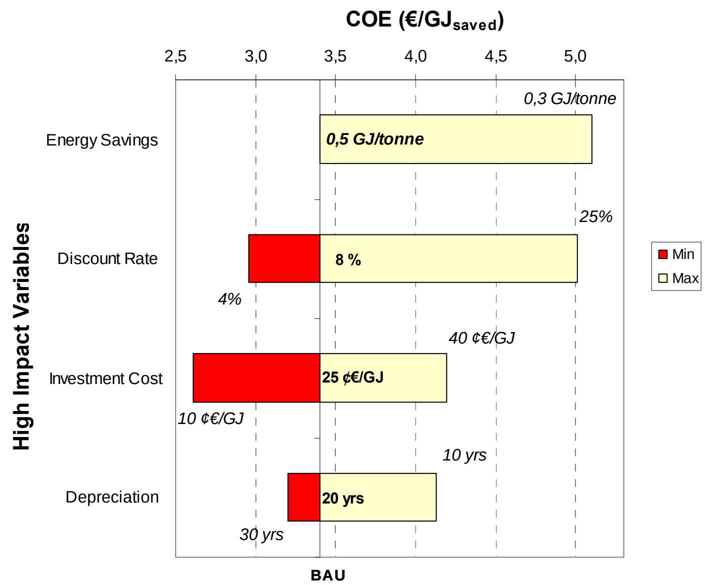
[47] As Ren suggests (2009), HiDICs "*…improve heat transfer by building heat exchangers between the stripping and rectifying sections*".

[48] Figure 2.2 shows the impact of major uncertainties over the estimation of COE for HiDIC + heat pump in ethylene manufacturing.

Figure 3.2. COE sensitivity: heat integrated distillation column (HIDiC)+heat pump for ethylene process



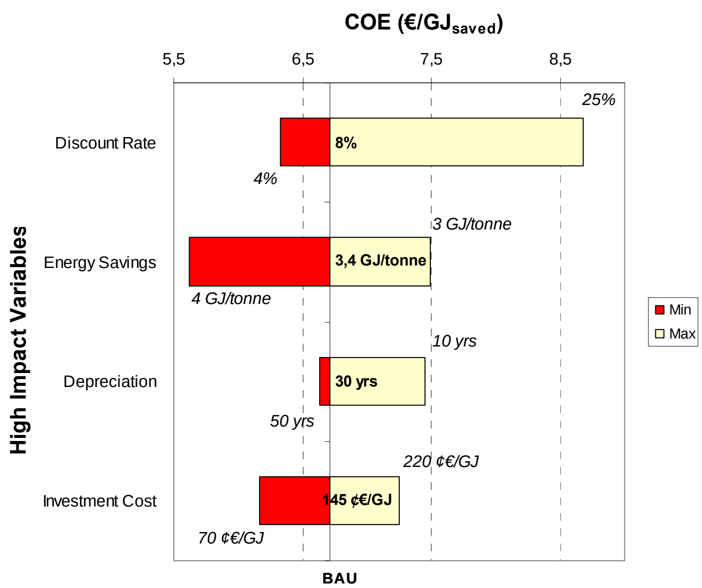
3.4.2 Gas turbine integration

Gas turbine integration leads to the export of both steam and electricity (Ren 2009a). Besides, it generates hot combustion gas for feedstock heating in the cracking phase of the process (viz. pyrolysis). It can save up to 3 to 4 GJ/tonne ethylene (Albano, Olszewski & Fukushima 1992).

In the ethylene manufacturing, gas turbine integration has a potential of more than 10 PJ of final energy savings. This, represents more than 10% energy efficiency improvement in the process, at costs in the range of 5.5 to 8.5 €/GJ_{saved} (around 6.5 €/GJ_{saved} under BAU conditions) [Figure

3.3][49]; and payback time shorter than 3 years. Gas turbine integration would require NPV investments of €510 million, with NPV benefits of €710 million from 2010 to 2020.

Figure 3.3. COE sensitivity: gas turbine integration for ethylene process



3.4.3 Heat recovery

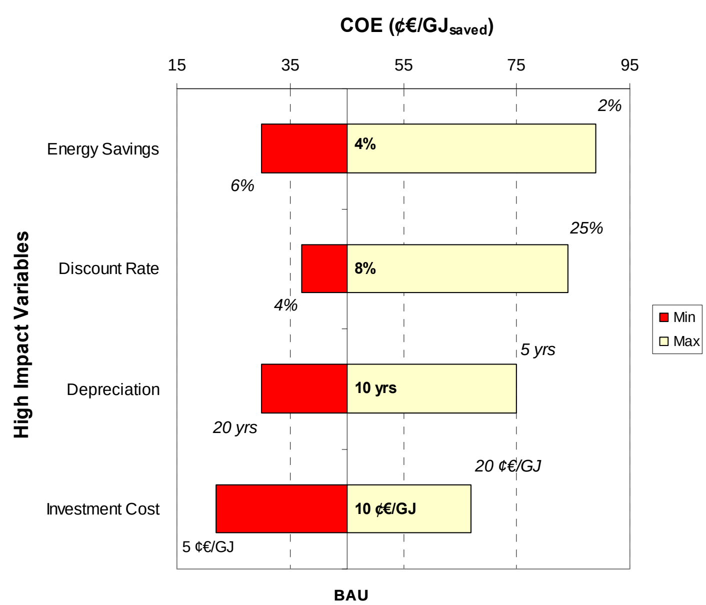
Heat recovery in the industry is widely used. While the measure is also common in the ethylene process, there is often still potential for more energy savings from this measure (i.e. more heat recovery). Heat exchangers are utilized in the chemical and petrochemical industry to provide efficient use of energy and to improve process control. Recent advances in the construction of heat exchangers (e.g. new materials that resist harsh environments (IPPC 2003), and novel designs and

[49] Figure 2.3 shows the impact of major uncertainties over the estimation of COE for gas turbine integration in ethylene manufacturing.

manufacturing techniques that increase tolerance to higher temperatures and pressures) can now allow capturing and using more heat from processes, therefore leading to more energy savings (Martin et al. 2000b). Based on that, heat recovery can lead to 2 to 6% in fuel savings at process level (i.d.).

For the ethylene industry in the Netherlands, heat recovery has a potential of almost 4 PJ of final energy savings. The measure would lead to around 4% improvement in energy efficiency at process level at COE in the range of 20 to 90 ¢€/GJ_{Saved} (45 ¢€/GJ_{Saved} under BAU conditions) [Figure 3.4][50]; pay back time for this option would be shorter than 1 year. Given current production capacity in the Netherlands, heat recovery in ethylene manufacturing would require NPV investments slightly above €10 million, with NPV benefits over €220 million from 2010 to 2020.

Figure 3.4. COE sensitivity: heat recovery for ethylene process



[50] Figure 2.4 shows the impact of major uncertainties over the estimation of COE for heat recovery in ethylene manufacturing.

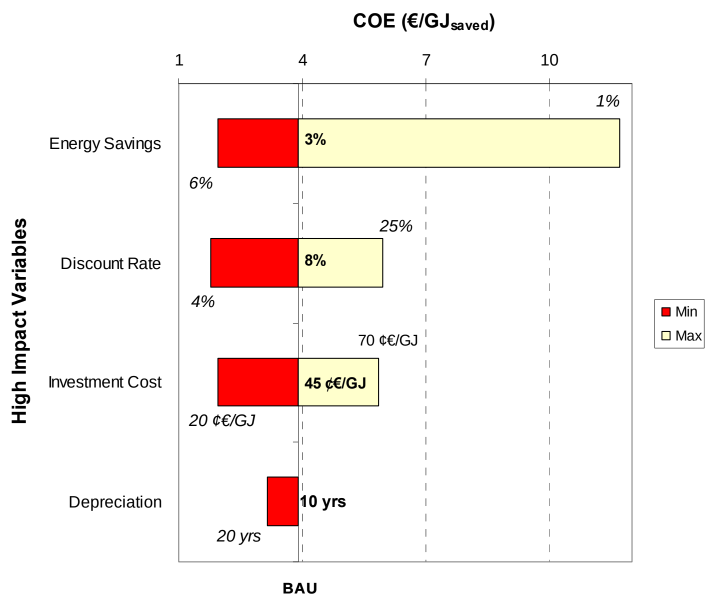
3.4.4 Process control and sensors

Improving process control through control systems and sensor technology not only improves energy efficiency, but also improve productivity, product quality and efficiency of a production line in nearly every industrial process (McKinsey & Company 2009). Applications of advanced control systems result in reduced downtime, maintenance costs, processing time, and increase resource and energy efficiency, as well as improved emissions control. In the industry, energy savings derived from the implementation of such technologies have been reported to be up to 6% (Martin et al. 2000b).

In the Dutch ethylene industry, further process control and sensors may lead to final energy savings close to 3 PJ. For instance, the improvement would represent a 3% energy efficiency improvement at process level at a COE in the range of 2 to 12 €/GJ_{saved} (4 €/GJ_{saved} under BAU conditions) [Figure 3.5][51]; estimated pay back time would be less than 2 years. Overall, the application of this measure in steam crackers in the Netherlands would require NPV investment costs in the order of €70 million with NPV benefits of about €180 million by 2020.

[51] Figure 2.5 shows the impact of major uncertainties over the estimation of COE for process control and sensors in ethylene manufacturing.

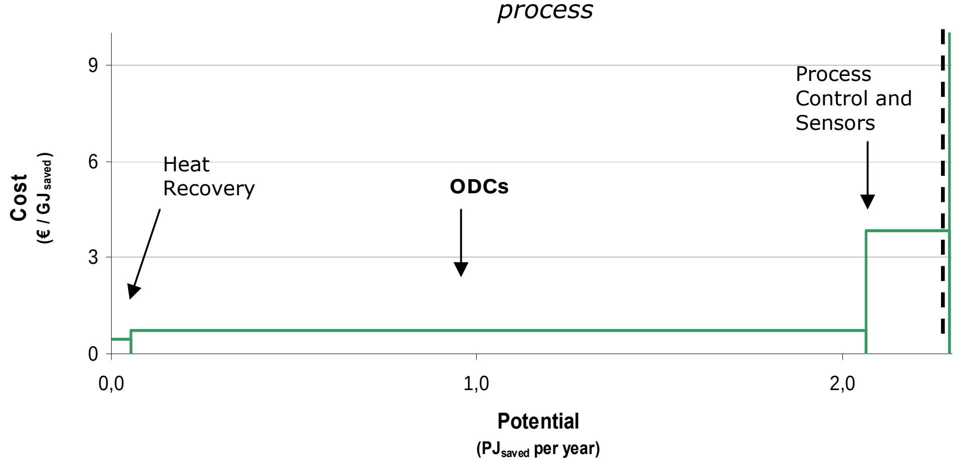
Figure 3.5. COE sensitivity: process control and sensors for ethylene process



3.5 Energy saving opportunities in chlorine production

In the Dutch chlorine industry, saving opportunities include retrofit improvement in processing, upgrading process control and increasing heat recovery [Figure 3.6]. An interesting process specific retrofit option for chlorine manufacturing is the implementation of oxygen depolarized cathodes (ODC) in electrolysis.

Figure 3.6. Chlorine energy abatement curve: measures and technologies, potential magnitudes, and incremental costs of options to reduce energy in process

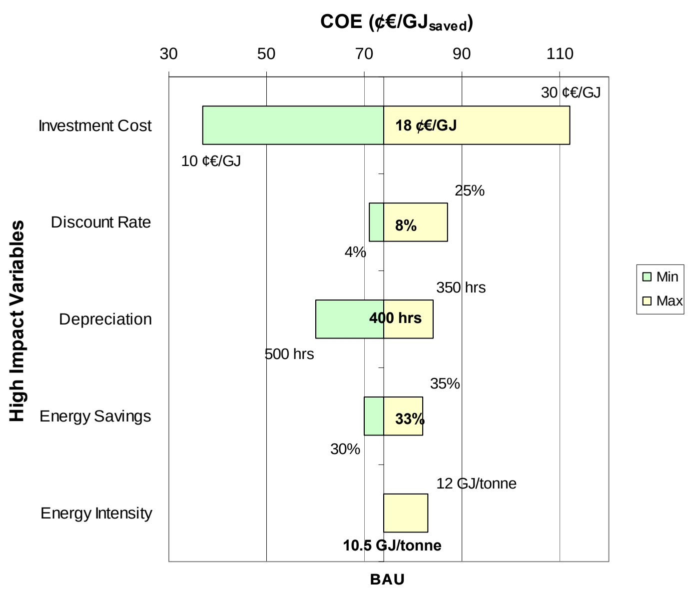


3.5.1 Oxygen depolarized cathodes (ODCs)

ODC's allows for reduction in energy intensity of membrane electrolysis by reducing voltage use (Moussallem et al. 2008). ODCs in chlor-alkali processes is an incorporation of fuel cell processes into the electrolytic membrane cell (IPPC 2001) where the cathode reduces oxygen instead of producing hydrogen (Morimoto et al. 2000). Therefore, ODCs have the potential to reduce the electric energy demand of the membrane cells by up to 35% (Kiros, Bursell 2008).

In the Netherlands ODCs have the potential to save up to 2 PJ of final energy in chlorine production; this is equivalent to almost 25% energy efficiency improvement at process level. The COE for ODCs would be in the range of 35 to 110 ¢€/GJ_{saved} (around 75 ¢€/GJ_{saved} under BAU conditions) [Figure 3.7][52], with a payback time shorter than 1 year. ODC's would require NPV investments of €10 million, with NPV benefits of €340 million from 2010 to 2020.

Figure 3.7. COE sensitivity: oxygen depolarized cathodes (ODC) for chlorine process



3.5.2 Heat recovery

For the chlorine industry in the Netherlands, heat recovery has a potential of around 100 TJ of final energy savings. In general, the measure would lead to around 1% improvement in energy efficiency at process level at COE in the range of 20 to 90 ¢€/GJ_{Saved} (45 ¢€/GJ_{Saved} under BAU conditions)[53]; payback time for this option would be shorter

[52] Figure 2.7 shows the impact of major uncertainties over the estimation of COE for ODCs in chlorine manufacturing.

[53] The impact of major uncertainties over the estimation of COE for heat recovery in chlorine, follows similar pattern as in Figure 2.4.

than 1 year. Based on current production capacity in the Netherlands, heat recovery in the chlorine industry would require NPV investments slightly above €200 thousand, with NPV benefits over €3 million from 2010 to 2020.

3.5.3 Process control and sensors

In the Dutch chlorine industry, further process control and sensors may lead to final energy savings close to 200 TJ. For instance, the improvement would represent around 3% energy efficiency improvement at process level at a COE in the range of 2 to 12 €/GJ_{saved} (4 €/GJ_{saved} under BAU conditions)[54]; estimated payback time would be less than 1 year. Overall, the application of this measure in chlorine manufacturing in the Netherlands would require NPV investment costs in the order of €10 million with NPV benefits of about €40 million by 2020.

3.6 Energy saving opportunities in PE production

Saving opportunities in the PE industry in the Netherlands[55] include process improvement by intensification, increasing heat recovery, and upgrading process control [Figures 3.8 and 3.9]. Both, LDPE and HDPE, have as promising energy saving technology the use of static mixers.

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[54] The impact of major uncertainties over the estimation of COE for process control and sensors in chlorine, follows similar pattern as in Figure 2.5.
[55] Only LDPE and HDPE industry.

Figure 3.8. LDPE energy abatement curve: measures and technologies, potential magnitudes, and incremental costs of options to reduce energy in process

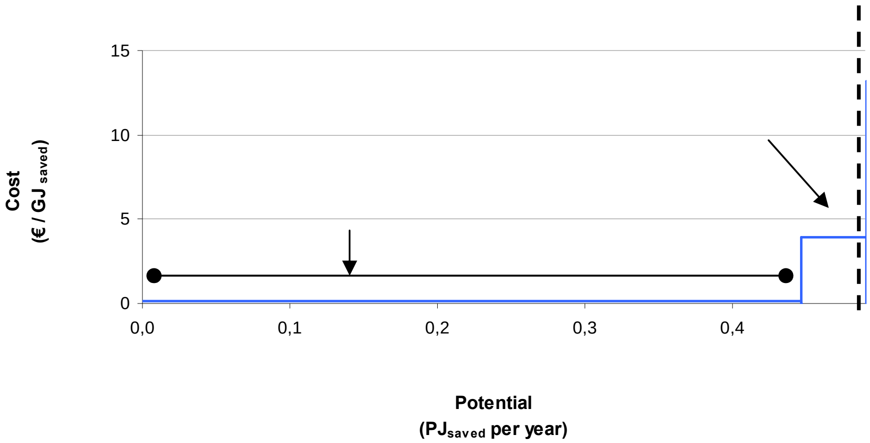
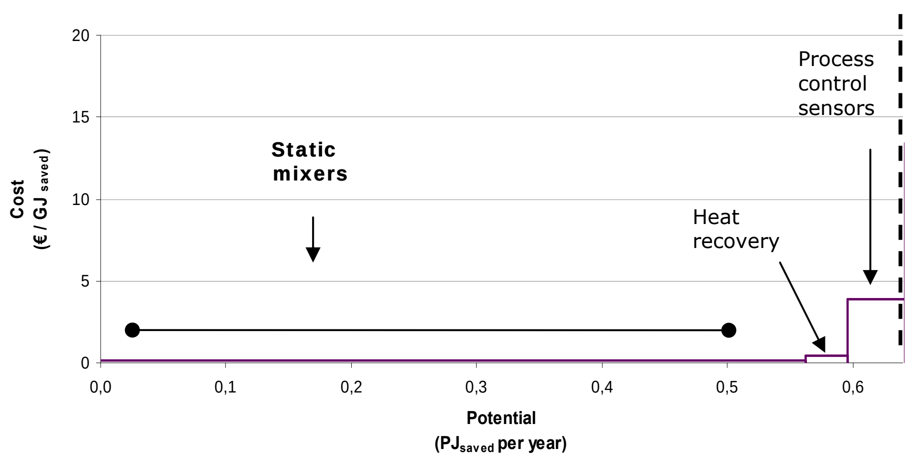


Figure 3.9. HDPE energy abatement curve: measures and technologies, potential magnitudes, and incremental costs of options to reduce energy in process



3.6.1 Static mixers for LDPE and HDPE

Static mixers reactors, also known as motionless mixers, provide excellent heat and mass transfer during polymerization (Thakur et al. 2003). The main feature of this equipment is its capability to improve mixing in different flow regimes (Cybulski 2008). The heat transfer comes from specific design of heat/cool coils and jackets around static mixers (Dickson 2008). These devices offer energy savings in mixing over traditional batch processes up to 90% (i.d.). On the other hand, when set in combination with gear pumps, motionless mixers can replace an extruder at the end of a polymerization line and account for 10 to 20% energy savings in extrusion (Thakur et al. 2003, Rosato 1998).

In PE processing in the Netherlands, static mixers have energy saving potential of about 1 PJ. On the whole, static mixers could improve LDPE energy consumption in more than 20%, whereas HDPE, in 35%[56]. COE for this technology would be in the range of 5 to 30 ¢€/ GJ_{saved} for LDPE (around 15 ¢€/ GJ_{saved} under BAU conditions); and, 10 to 60 ¢€/ GJ_{saved} for HDPE (around 20 ¢€/ GJ_{saved} under BAU conditions) [Figures 3.10 and 3.11][57]. In average, payback time for this type of technology would be less than 1 year; NPV investments required would be in the order of €2 million, with NPV benefits of €200 million from 2010 to 2020[58].

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[56] Figures consider energy savings by mass and heat transfer (mixing) improvement and extrusion up grading (gear pump + static mixer).

[57] Figures 2.10 and 2.11 show the impact of major uncertainties over the estimation of COE for static mixers in PE manufacturing.

[58] Large differences in benefits and costs are due to low capital costs and high energy savings from static mixers. For instance, literature suggests that capital costs of static mixers can be up to 90% lower than capital costs for mechanical mixers (Cybulski 2008). Regarding savings, they could be in the order of 60% in final energy use (combining savings in mixing and extrusion).

Figure 3.10. COE sensitivity: static mixers for LDPE

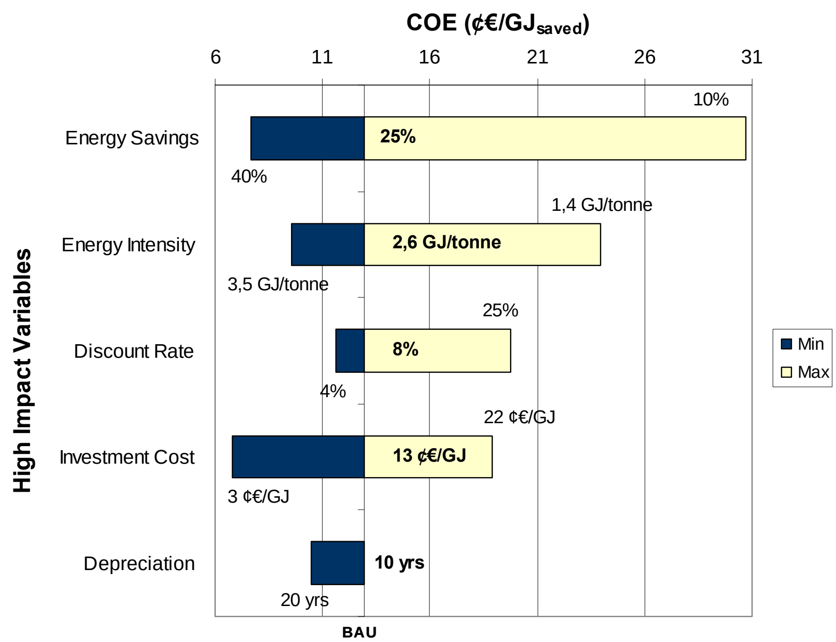
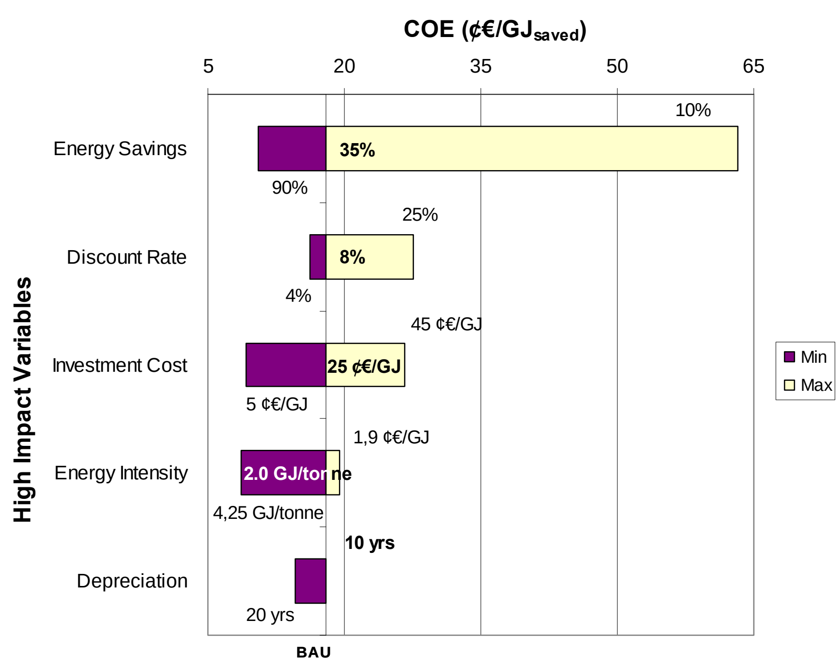


Figure 3.11. COE sensitivity: static mixers for HDPE



3.6.3 Heat recovery

In the Dutch HDPE industry, further heat recovery has a potential of around 30 TJ of final energy savings. In general, the measure would lead to around 2% improvement in energy efficiency at process level at COE in the range of 20 to 90 ¢€/GJ_{Saved} (45 ¢€/GJ_{Saved} under BAU conditions)[59]; payback time for this option would be shorter than 1 year. Given HDPE production capacity in the Netherlands, heat recovery in HDPE manufacturing would require NPV investments slightly above €100 thousand, with NPV benefits over €3 million from 2010 to 2020.

2.5.3 Process control and sensors

In the PE industry in the Netherlands, further process control and sensors may lead to final energy savings close to 90 TJ. For instance, the measure would represent energy efficiency improvement at process level of about 3% in HDPE and over 2% in LDPE. For this measure, COE would be in the range of 2 to 12 €/GJ_{saved} (4 €/GJ_{saved} under BAU conditions)[60]; estimated payback time would be less than 1 year. Overall, the application of this technology in PE production in the Netherlands would require NPV investment costs in the order of €2 million with NPV benefits of about €20 million by 2020.

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[59] The impact of major uncertainties over the estimation of COE for heat recovery in HDPE follows similar pattern as in Figure 2.4.

[60] The impact of major uncertainties over the estimation of COE for process control and sensors in PE follows similar pattern as in Figure 2.5.

3.7 Energy saving potentials in the energy intensive IChem-NL: summary of results

Assuming a 2.4% annual growth in the chemical sector (Daniëls, Kruitwagen 2010), the ethylene manufacturing in the Netherlands is expected to consume around 115 PJ of final energy by 2020[61]. Savings for this process are in the order of 20 PJ. The measures presented have the potential to save 20% process energy; this would require NPV investments of €630 million, but would generate NPV benefits larger than €1 billion; in average, the potential would pay back in less than 2 years.

By 2020, Dutch production of chlorine will be close to 1 million tones (assuming a 2.4% annual growth in the chemical sector); such amount, will demand over 10 PJ of final energy[62]. Energy efficiency improvement in chlor-alkali processes has a potential of more than 2 PJ of savings. The package of measures previously discussed, would represent almost 30% improvement in process energy use, at required NPV investment costs close to €20 million and NPV benefits of about €380 million by 2020; in average, potential would pay back in less than 1 year.

Finally, PE production in the Netherlands is expected to consume over 4 PJ of energy by 2020 if a 2.4% annual growth is considered[63]; where

[61] Other assumptions are that process energy intensity will stay at 28 GJ/tonne ethylene; and, operation rate will be at 85%.

[62] Other assumptions are that process energy intensity will stay at 12 GJ/tonne ethylene; and, operation rate will be at least 85%.

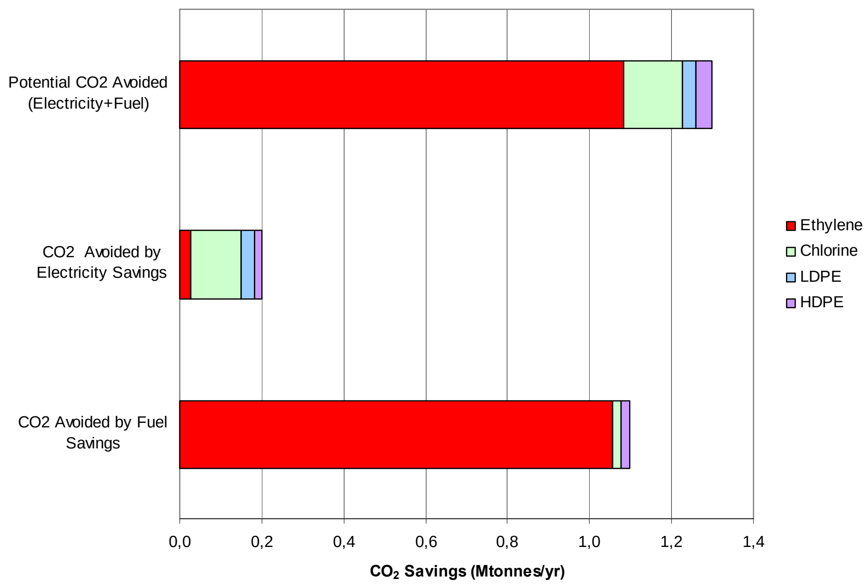
[63] Other assumptions are that process energy intensity will stay at 2.1 GJ/tonne HDPE and 2.6 GJ/tonne LDPE; and, operation rate will be at 85%.

production of LDPE and HDPE will account for 2 PJ each[64]. The savings potential for these processes are above 1 PJ of final energy (LDPE and HDPE together). The measures presented have the potential to save energy in LDPE process by 25% and HDPE by 40%; the would require a combined NPV investments of about €5 million, but would generate NPV benefits up to €220 million; in average, the potential would pay back in less than 1 year.

Overall, theoretical energy saving potential found in this research amount up to 23 PJ by 2020. This would reduce chemical industry's final energy consumption to a level 7.2% lower than consumption in 2008 and 7.4% lower than in 2020[65]. By implementing the options previously discussed, over 1 million tonnes of CO_2 could be saved (close to 15 million tonnes of cumulative CO_2 avoided by 2020) [Figure 3.12][66]. Capturing this potential would save over €250 million per year in energy costs, though between 2010 and 2020 it would require NPV investments in the order of €650 million yielding total present value savings close to €2 billion. At an average electricity and gas price of 9.2 ¢€/kWh_e and 3.3 ¢€/kWh_g, such investments would have an average payback time of about 1 year[67] under BAU[68] conditions. A summary of the results is stated in Table 3.3.

[64] Other types of PE (e.g. LLDPE) are not considered.
[65] The IChem-NL is expected to consume around 371 PJ of final energy by 2020 (excluding non energetic use)(Daniëls, Kruitwagen 2010). Projection including established national and European policies.
[66] Based on emission factors of: 0.6 tonnes of $CO_2/GJ_{Natural\ Gas}$; and, 1.0 tonnes of $CO_2/GJ_{Solid\ fuels}$.
[67] Only measures with an IRR over 35% were considered.
[68] Business as usual: discount rate 8%, depreciation 10 years.

Figure 3.12. Potential CO_2 savings: contribution by energy savings in applied processes



Process	**$SAVE_{Total}$ (in PJ)**	**Share of energy use in IChem-NL**		**Total Annual benefits of savings (M€)**	**$NPV_{by\ 2020}$ Inv.Costs (M€)**	**$NPV_{by\ 2020}$ Benefits (M€)**
		2008	*2020*			
Ethylene	20	6.1%	6.3%	180	630	1200
Chlorine	2	0.7%	0.7%	60	20	380
PE[69]	1	0.4%	0.4%	30	5	220
Totals	**23**	**7.2%**	**7.4%**	**270**	**655**	**1800**

Table 3.3. Summary of results.

Although options proposed in this research cannot be seen as exclusive[70], the estimates presented may give a good reference about the contribution to energy efficiency improvement -in general- process specific

[69] LDPE and HDPE combined.
[70] The analysis followed in this research was rather general. Indeed, the scope of this study was limited to present sources of energy savings, comparative incremental costs and relative magnitudes. A more extensive and detailed review of energy saving opportunities at company level would give a more precise background that could be used for more accurate energy saving forecasts in the energy intensive chemical industry.

savings would have within the IChem-NL. Nonetheless, it is worth to mention that, comparing these findings to reference literature viz. World's best practice technologies (BPT), results showed in the previous section are compatible [Table 3.4].

Process	Energy Intensity (World BPT, GJ/t)	Reference	Energy Intensity (European BPT, GJ/t)	Reference	Potential Energy Savings, based on literature [71,72]	Cumulative $SAVE_i$ in this report [71]
Ethylene	13,4	(Saygin et al. 2009)	<25	(IPPC 2003)	<45%	20%
Chlorine	8,6	(IEA 2007b)	10,7	(IPPC 2001)	20%	30%
LDPE	1,4	(Saygin et al. 2009)	2,3	(IPPC 2003)	40%	25%
HDPE	1,9	(Saygin et al. 2009)	4,3		55%	40%

Table 3.4. Summary of energy saving potentials at process level, as proposed in literature and in this report.

[71] Potential energy savings considering ethylene, chlorine and PE manufacturing in the Netherlands are BPT.
[72] Percentages expressed as per GJ/tonne of product.

IV. Investment decision making in the energy intensive IChem-NL: barriers to investment in energy saving technology

In this research, barriers to investment in energy savings inside the energy intensive IChem-NL were identified and evaluated empirically. The next chapter presents the results. Firstly, a general review of drivers and barriers to investment in energy savings will be presented[73]. Next the methodology for estimating potential barriers as well as the acceptability of policy instruments at company level is introduced. Finally, the findings will be listed.

4.1 Long term returns: a major driver to investment in energy saving technology

In general, even though energy costs might represent an important share of total production costs in the IChem-NL[74], investments purely

[73] Drivers are defined as *"factors that positively affect a firm's intention for innovation and therefore assist innovation activities"*. Barriers, as *"factors that negatively affect a firm's intentions and therefore hamper innovation activities"*(Ren 2009b).

[74] For instance, utilities cost in ethylene production account for more than 20% of total production costs (sic.). In the case of chlorine, more than 30% (sic.).

aimed at energy savings account for less than 10% share of total investments (De Groot, H. L. F., Verhoef & Nijkamp 2001). This is not hard to conceive, understanding that energy efficiency is not the main concern of chemicals manufacturers[75]; whereas most firms consider energy efficiency as an important factor in their investment decisions, they do not rank it as the highest in their priorities.

Certainly, the most important driver to investment in energy efficiency is long term returns. Investments are performed in order to increase future flow of capital services. That is, firms invest in order to secure future streams of financial benefits (Common, Stagl 2007). From an economic perspective, it is clear that investments that bring along positive cash flows will score higher in a project appraisal[76]. Delivering attractive long term returns ensures firm's competitive position and shareholder value (Tester et al. 2005). Therefore, projects that convey complementary benefits such as increased capacity and improved product quality are preferred at first over those that do not.

Mostly, investment in energy efficiency is not exclusively dependent on long term returns[77]. In reality, a wide range of failures also discourage businesses from embracing energy efficiency, as well as impede these investments from happening to its maximum potential. Overall, these failures constitute important barriers to investment in energy efficiency.

[75] A chemical producer makes its living from selling chemical products, not from saving energy in their manufacturing (sic.).
[76] Project appraisal is the decision making process in which a company decides which investment project to undertake, and which not to undertake (Common, Stagl 2007)
[77] Other drivers enhancing investment decision making are increase in sales, efficiency production increase in processes, profit increase and improvement of environmental image among others.

4.2 Barriers to investment in energy saving technology

There are several barriers to the implementation of energy efficiency improvement measures. For instance the industry faces three major types of barriers e.g. economic, socio-economic (behavioral) and, technological barriers[78] (Sorrell et al. 1999). These barriers are manifested in several forms, and can be considered as the main explanation for why investments in energy savings are not undertaken.

4.2.1 Economic barriers

Economic barriers are defined as the set of market, public policies and institutional failures that inhibit the diffusion of energy saving technology (Sathaye, Bouille 2003). Regarding this economic cluster, four barriers may be distinguished:

1) Availability of external/internal capital;
2) Change in energy prices;
3) Economic trend or market situation; and,
4) Discontinuation of economic policy instruments.

Firstly, availability of external/internal capital refers to the access to capital that a company may have in order to raise sufficient funds for an investment to go ahead (Schleich 2007). That is, the capability to acquire financial means either internally (e.g. own reserves, fixed part of

[78] These barriers can be theoretically explained through neo-classical economics, transaction cost economics, psychology, decision theory, and organizational theory. Detailed explanation of these aspects is outside of the boundaries of this study.

investment budget, etc) or externally (e.g. bank loans, emitting stock certificates, use of governmental subsidies, etc). Restrictions to the availability of capital are identified, perhaps, as one of the important hurdles to invest in general, and for energy saving technologies specifically.

Secondly, changes in energy prices also play a crucial role when discouraging investments in energy efficiency. In general, it is expected that high energy prices in the future will ensure the implementation of energy saving technology. To illustrate, when the price of energy increases, investments in energy savings are associated with high cost savings (Masselink 2008). However, given the high unpredictability of future energy prices, there is a still large uncertainty about the speed or durability of this type of phenomena (Jaffe, Stavins 1994b). Furthermore, even when energy savings (due to high energy prices) are economic attractive, investment in these is not mandatory to happen[79].

Thirdly, as an external risk, the economic trend and the market situation may also constitute a crucial obstacle for energy saving investments to take place. A positive market expectation, or economic trend, is a decisive condition for investing in energy savings; economic benefits are only positive in markets where investment costs can be recovered in product price. For example, on the topic of investments in energy savings, reducing energy costs would have a direct impact on production cost (viz. decrease in utilities cost); consequently, increasing

[79] There is literature that suggests that even when energy prices are high, firms do not invest in energy efficiency (Koetse, Groot & Nijkamp 2006).

the competitiveness and comparative advantage of such product within the market[80]. In contrast, stagnating markets risk innovation and investment, and instead encourage firms to rely on depreciated capital to maintain low production costs (e.g. extending the time life of technologies by maintenance and minor improvements instead of investing in new technologies).

Finally, discontinuation of economic policy instruments may also hinder the development of investments. In some cases, the deployment of specific technologies depends upon the aid of external means viz. economic incentives. So, when in place, such kind of policy instruments can encourage energy savings and innovation. Then, economic incentives, such as subsidies or tax rebates, may contribute substantially to financing the cost of a particular investment. However, under a horizon of policy uncertainty (in the medium or long term), firms may opt for not including such aids in their project appraisals (van Swigchem et al. 2002), judge them as not financially manageable (Hennicke 1998), or consider them as low impact for investment decision making (Aalbers, Groot & Vollebergh 2004). As result, stochastic policy instruments can lead to skepticism in firms, and end up with no influence on investment decision making e.g. motivating firms to invest in energy efficiency.

[80] In this context, comparative advantage refers to the capability of the firm to produce its good at lower opportunity cost than others.

4.2.2 Socio-economic barriers

Socio-economic barriers refer to the set of obstacles that discourage individual and collective behavior viz. habits, attitudes and social norms and, vested interests towards the diffusion of energy saving technologies and measures (Sathaye, Bouille 2003). In view of this, the socio-economic cluster includes the following barriers:

1) Information on energy use, and energy saving opportunities and technologies;
2) Rules of investment decision making; and,
3) Budget restrictions and investment priorities.

To start with, lack of information or poor availability of it, may lead to missed cost effective opportunities (Schleich 2007). Certainly, companies that do not manage right information on energy efficiency opportunities[81] or energy performance of technologies may under invest in energy savings (i.d.). That is, without full knowledge of energy consumption, there is no incentive to invest in energy efficiency (Masselink 2008). Consequently, imperfect information is likely to lower investments in improving energy efficiency than what it would be with symmetric information.

On the other hand, in order for any investment to be successfully considered, it has to follow defined capital budgeting procedures. Common

[81] In this case, energy saving opportunities refers to those options related to housekeeping, quality control, and culture on energy use (technical operation). In the contrary, with energy saving technologies it is meant those energy saving opportunities that involve technological innovation at process level (without considering technical innovation at operational level).

practice in industry is to evaluate projects on the basis of cost-benefit analysis such as net present value (NPV), pay back time (PBT)[82], or internal return (IRR)[83]. In general, whereas NPV and IRR are used as key indicators of the profitability of a project; PBT is used as reference of the economic risk of an investment. Whatever the evaluation is followed, the tendency is to attribute strict requirements for energy saving projects to pass such tests. For instance, to approve a project, it is common practice in industry to demand for investments that deliver IRR higher than 25% and, under market uncertainty conditions (viz. investment risk environments), PBT as short as 1 year. One of the reasons that may explain this behavior is that top management does not consider energy-cost savings as a strategic priority.

Finally, closely related to the former barrier (and also considered a driver), budget restrictions and investment priorities may also hurdle energy saving projects to be developed. As discussed previously, within their financial boundaries, companies invest according to specific requirements; given a capital rationing (Rohdin, Thollander & Solding 2007, De Groot, H. L. F., Verhoef & Nijkamp 2001), they allocate means for investments according to a stringent priority list (refer to section 3.1) Certainly, this situation differs among companies. However, due to this scheme, investments out of that list are simply not considered most of the time (as is the case for projects exclusively related to energy savings).

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[82] PBT is an indicator of the ability of a project to "pay for itself" though annual savings or benefits that the investment creates .

[83] IRR is an indicator of the rate of interest that a given investment project requires in order to be marginal i.e. in order to have no effect on a firm's net worth.

4.2.3 Technological barriers

Technological barriers are defined as the set of obstacles that limit the implementation of already demonstrated energy saving technology (Sathaye, Bouille 2003). Within this cluster, remarkable barriers are:

1) Technology investment irreversibility;
2) Technology fitting in actual process;
3) Specific installations costs;
4) Loss of economic benefits; and,
5) Overhead costs (transaction costs) [84].

At first, given the irreversibility of an investment, it may be rational not to invest in a specific technology that appears profitable (van Soest, Bulte 2001). In other words, it is plausible to postpone an investment, at defined short term costs, if the long term benefits of a better technology can be enjoyed in the future. From a techno-economic perspective, the fear that firms have that future technologies will be significantly better constitutes an impediment that not only prevents the development of investments but also, imminently, the development of innovators and early adopters (Rogers 1995).

Secondly, uncertainty associated with the compatibility between new technologies and current production processes is also considered an important barrier (Masselink 2008). Indeed, relying on already known or

[84] Certainly, loss of economic benefits and overhead costs could also fit in the category of economic barriers. However, in this study such were included in the category of technological barriers given that they are seen as economic consequences of the failure in technology (i.e. the barriers are originally related to the existence of technological shortcomings).

demonstrated technologies and layouts, and operational control, is considered to be more important than the potential benefits from implementing new technologies (Ren 2009b). This is because integration of new technologies may add complexity to process, reduce flexibility or cause incompatibility with other existing technologies in operation. Besides, process layout often does not allow for retrofitting new equipment i.e. there are spatial restrictions. Therefore, the full benefits from implementing new equipment in existing configurations is often limited to the use of new "already known" equipment i.e. repairing old equipment rather than installing new technology.

Next, specific installation costs are those not embedded in the investment cost of a new technology, but that are indispensable for the technology to fit in an actual process. Commonly, this costs involve expenses for integrating the technology into a given process layout, as well as the maintenance of such technology. On the other hand, overhead costs are the indirect costs of an investment. These, include: 1) costs of diminishing of an utility associated with new technology choices (e.g. problems with safety, noise, quality, or lower reliability or quality); 2) costs involved in individual technology decisions (e.g. costs for additional staff or retraining, disruptions and inconveniences, etc); and, 3) general costs of technology management (e.g. costs of employing specialists, information systems, auditing, etc) (Schleich 2007). On the whole, such costs –installation and overhead costs- may hurdle the potential benefits of a new technology and, consequently, its adoption.

As a barrier, loss of economic benefits (viz. stop of generating financial gains) may also diminish the attractiveness for investing in new technology. Loss of economic benefits involves the costs associated to the production interruption and/or failure (viz. downtimes). For large scale processes, the costs for disruptions and shutdowns can amount to thousands of millions of dollars per month for a plant (Burchmore, Ayscough & Gendebien 1993). Therefore, concerned about outweighing the benefits of new technologies from improving processes, plant operators are often reluctant to adopt technological changes, whether innovative or not (Ren 2009b).

4.3 Policy instruments to overcome barriers to investment in energy efficiency improvement

Explained by a neoclassical economic reasoning, the existence of the previously discussed barriers "…*stems from the failure of the institutions of which markets consist, and in which they are embedded, to incorporate the full cost and benefits of economic activities."* (Common, Stagl 2007). Indeed, according to this economic reasoning, such failures appear when institutions miss to require economic actors (viz. producers and consumers) to take responsibility of the consequences of their economic activities (e.g. in this case, responsibility of their energy use consumption or energy efficiency improvement). Subsequently, this failure leads to a suboptimal private and social cost[85].

From a policy perspective, there are different means (institutions) that could persuade economic actors to take such responsibility. That is, there are instruments that might contribute to overcome these barriers. For example: (1) decentralized instruments, such as moral suasion, property rights and liability laws; (2) command and control instruments (direct regulation), such as technology standards combined with enforcement; and (3) market-based instruments, such as emission taxes, subsidies and tradable permits (i.d). As a whole, these measures intend to (to different extent): (1) achieve environmental improvement (e.g. reduction in energy use and, subsequently, CO_2 emissions); (2) cause the lowest possible cost for economic actors (e.g. energy intensive chemicals firms and the government); and (3) avoid negative, and initiate positive, impacts in other areas of society (e.g. employment or income distribution) . In this way, within the context of energy savings, policy instruments can achieve a given level of efficiency improvement at lowest overall cost (viz. optimal private and social cost) by creating a framework that enables firms to respond according to their ability to develop improvement[86].

[85] E.g. private profit maximising decisions that are not socially (allocatively) efficient .
[86] As Common and Stagl (2007) suggest, "*ultimately, firms are either rewarded or penalised for their efforts*".

4.4 Methodology for estimating potential barriers to investment in energy saving technology and acceptability of policy instruments

To acquire insight into the relevance of barriers to energy efficiency investment decision making, 13 energy specialists were surveyed[87] and interviewed about the topic. During the surveying[88], specialists were asked to rank different barriers (viz. economic, socioeconomic and technological barriers) related to economic and behavioral aspects. For this objective, the method of pair-wise comparison was used. This method results in a matrix with (X-1) comparisons (Appendix C). For instance, the respondents were requested to define, whether barrier A or B would impede investment in energy efficiency more strongly. Then, in the case barrier A was selected, 1 point would be attributed to it. Otherwise, one point would be attributed to B. This procedure leads to a structured and objective ranking of the barriers within the respective categories (viz. individual weight of influence). Subsequently, the average value of all respondents was estimated to generate a perspective of the relevance of the barriers (viz. average weight of influence). Later, with the ranking of barriers revealed, respondents were asked to explain the reasons about their choices during the interviews.

Alternatively, to estimate the acceptability of policy instruments at company level, the 13 energy specialists surveyed were also asked to

[87] For quantitative matters, this report will only include results of 10 out of the 13 surveys; by the time the report was prepared only 10 surveys were returned. Nonetheless, the assessment does include insights from the 13 interviews.
[88] A sample of the survey questionnaire is included in Appendix D.

state –in their view- which policy instruments would have larger influence on energy efficiency investment decision making. For that purpose, respondents were requested to rate 9 policy instruments on the basis of their likelihood to positively influence energy savings project appraisals (e.g. from 0 to 4, being 0 very unlikely to influence and 4 very likely to influence; refer to Appendix C). From their answers, a hierarchy of acceptable instruments was generated. At last the outcome was discussed in more detail with respondents during the interviews.

4.5 Consistency check and inter rater reliability

In order to check the answers of the respondents for consistency and reliability, two extra tests were performed. In general terms, each respondent answered 26 pair-wise comparisons to come to an overall ranking of barriers. Ideally within this approach, one barrier should be always preferred over another in each cross comparison; in that case, the most preferred barrier should obtain the highest rating (maximum points in the score), whereas the least preferred should receive the lowest (zero or few points in the score). However, sometimes preference cannot be attributed to any of the barriers being compared (i.e. both barriers were preferred equally). Although in theory barriers should be consistent or logically ranked, when no clear distinction is made, barriers can have same ratings. In this sense, consistency of 100% would represent an absolute logical ranking in a selection whereas, for instance, a 50% would indicate circularity in reasoning given that within the selection no ranking could be assigned[89]. In other words, those respondents that answered the 26 pair wise-comparisons (maximum score) were 100% consistent; while those that answered only 13 (low score) were 50% inconsistent. For the case of rating policy instruments, the similar reasoning applied[90].

In this research, most of the respondents showed acceptable consistency (average 96% for barriers; 93% for policy instruments; [Figures 4.1 and 4.2]. Although some respondents felled slightly short (below 90%), the level of inconsistency was accepted for the purposes of this study (above 80%). Inconsistencies can indicate (1) low attention at the side of the respondents, and (2) difficulties in ranking barriers and instruments given their proximity (i.e. closeness among barriers) (Masselink 2008). Nonetheless, analyzing the outcome of the study including all respondents (viz. above 80% consistency) with the outcome of the study disregarding inconsistent respondents (viz. above 90% consistency), no significant difference was found.

[89] E.g. Barrier A is regarded more important than barrier B; barrier B, more than C; but, barrier C is higher valued than barrier A.
[90] Respondents that qualify the 9 instruments were 100% consistent whereas those that qualify less achieved less level of consistency.

Figure 4.1. Consistency of rating by respondents: barriers to investment in energy saving technology

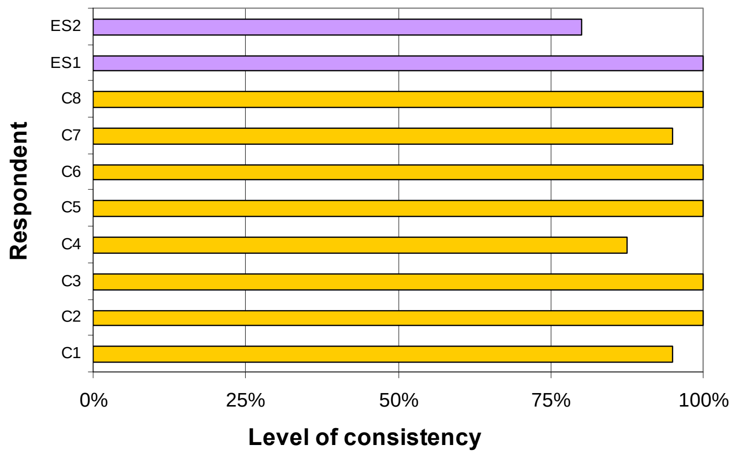
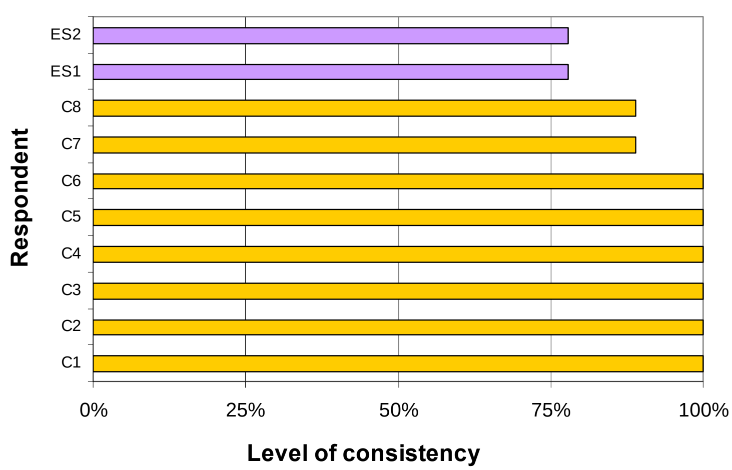


Figure 4.2. Consistency of rating by respondents: acceptability of policy instruments



The second test applied was related to the inter reliability of raters i.e. agreement among respondents. While weighted average of influence of barriers and policy instruments are good indication of relevance over investment decision making, agreement among different respondents may give an idea about the robustness of such relevance. To make such indication, answers were evaluated statistically under the Fleiss' kappa technique (Fleiss 1971). Fleiss' kappa, related to the Cohen's kappa statistic and the Scott's pi statistic, describes a technique for obtaining inter rater agreement when the number of raters is greater or equal than two. According to Fleiss (1971), indices of agreement can be used to correct for the *"…extent of agreement expected by chance alone among raters"*. In this way, the extent of agreement (k) among a defined number of raters over defined subjects and under a set of categories would be complete if k equals 1; whereas incomplete as it gets closer to 0 (Table 4.1).

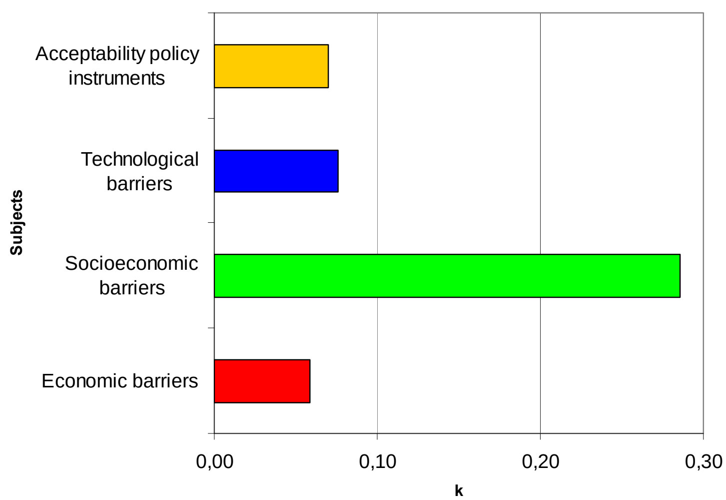
κ	**Interpretation**
< 0	Poor agreement
0.0 – 0.20	Slight agreement
0.21 – 0.40	Fair agreement
0.41 – 0.60	Moderate agreement
0.61 – 0.80	Substantial agreement
0.81 – 1.00	Almost perfect agreement

Table 4.1. Extent of agreement: interpretation of Fleiss' kappa values.

In this study, the inter rater reliability check revealed that agreement among respondents when qualifying different barriers and policy instruments was low [Figure 4.3]. This gives an impression about the diversity of opinions when attributing level of influence of one barrier (or policy instrument) over investment decision making when comparing it with another. Certainly, this outcome suggests that caution must be given to the analysis and interpretation of the results achieved in this research.

In other words, it would be unrealistic to come to a generally accepted conclusion about the relevance of the different barriers and policy instruments over energy saving investments decision making. Still, the next sections will provide an overall perspective of the results of this research and discuss the relevance of its findings over investment in energy saving technology.

Figure 4.3. Inter rater reliability: Fleiss' kappa values for barrier clusters and acceptability of policy instruments



4.6 Economic barriers in the IChem-NL

For the energy intensive IChem-NL, it is hard to convey which economic barrier is the most important [Figure 4.4]. Given that barriers are not exclusive i.e. they can be all interlinked, it can be difficult to highlight definitively one barrier over all. Nonetheless, under BAU conditions, there is a slight tendency for some obstacles to influence more largely over investment decision making.

On the whole, based on the influential role a barrier may have over investment decision making, it is fair to consider that change in energy prices (score 2.9), the economic trend and market situation (score 2.4), and –to a smaller extent[91]- availability of external and internal capital (score 2.4) might be the main concerns of business leaders in the chemical sector when planning to invest on energy savings [Figure 4.5][92]. For this to happen, it is certain that such barriers have a direct impact on the economics viz. profitability of energy saving investments. For instance, an increase in energy prices enlarges the attractiveness of an investment in energy efficiency (i.e. at higher energy prices, energy saving projects become more profitable). In addition, high energy costs may also trigger the accessibility to capital (i.e. economic attractive projects will always bring investors). On the other hand, it can also impose a negative impact on the situation of a company on the market (e.g. globally, the comparative advantage of energy intensive producers is very sensitive to energy price fluctuations; the higher, the easier for a company to lose its competitiveness).

[91]However, during interviews some respondents clarified that availability of capital should not be considered –strictly- as a major barrier. The reasons given were: (1) when an investment project is economic attractive, there are always people willing to invest in it (viz. easiness to acquire external funding); and, (2) availability of capital depends strongly to the price of energy, and the economic trend and market situation. Perhaps, these two reasons might be also justified by the size and importance within the chemical market of the companies included in this study.

[92] Based on the inter rater reliability assessment, this can be accepted statistically. Nonetheless, it is important to mention that such tests measured the agreement among respondents over the relevance over a define barrier within a cluster of barriers. Although agreement upon the relevance of different barriers was not really strong among respondents, still a tendency to choose one barrier over the others seemed to be consistent; this statement applies for the three clusters of barriers analyzed in this research.

Figure 4.4. Economic barriers: weight distribution based on interviewees criteria (normalized)[93]

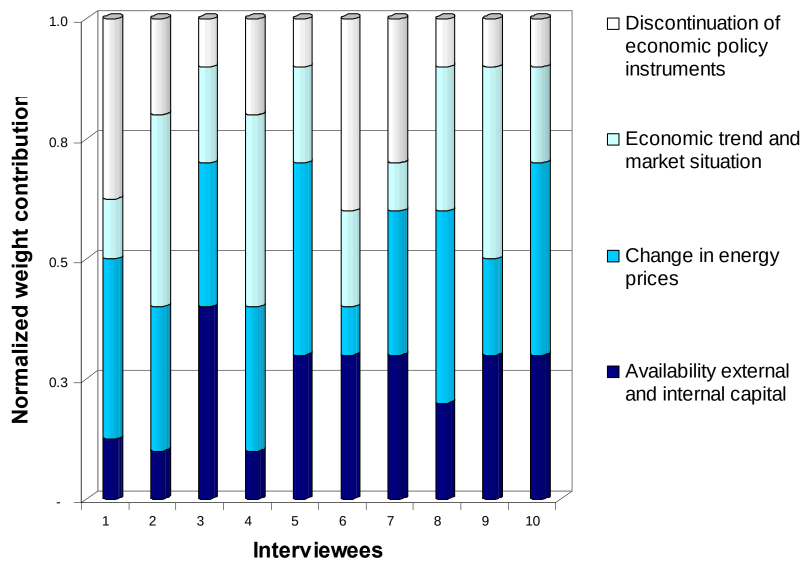
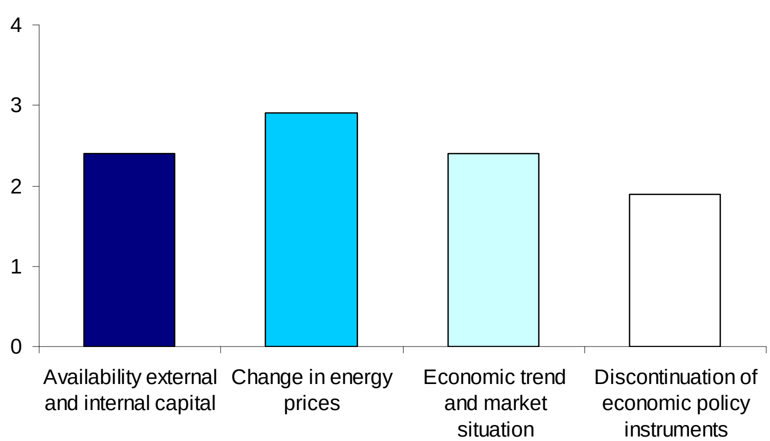


Figure 4.5. Economic cluster: average scores for barriers (Max. score =4)



[93] In the graph, "C" stands for company representative¨; "ES", for energy specialist.

4.7 Socio-economic barriers in the IChem-NL

Among Dutch energy intensive chemical manufacturers, there is a similar view about the impacts of socio-economic barriers on investment decision making [Figure 4.6]. In general, given the rather large size of the companies including in the survey, experts consulted do not consider barriers related to imperfect information as important obstacles. This is simply because large companies often have several means to acquire information e.g. process control and monitoring; labor exchange among facilities; R&D; external audits; and, constant external/internal communication (onsite colloquiums, international conferences and congresses, specialized workshops, etc).

In contrast to information matters, budget restrictions and investment priorities (score 4.3), followed by rules of investment decision making (score 3.9), are the most likely hurdling barriers within the cluster [Figure 4.7]. In the chemical industry, the amount of capital to invest is limited. That is why, in order to maximize the benefits of an investment, project appraisals have to be performed based on strategic criteria that, firstly, ensures the completion of legal and structural needs and, secondly, returns major economic margins (i.e. budget restrictions and investment priorities). However, if that capital is to increase to finance other projects e.g. energy efficiency projects, fund raising has to increase as well. Conventionally, as the amount of internal capital is also restricted, only through rising external funds capital can be enlarged, e.g. by acquiring larger debts. Debt in the industry builds a climate of insecurity for investors to put money on projects. So, in order to manage the risk of their investments, more stringent financial requirements are demanded (i.e. higher IRRs). Consequently, for a project to successfully come out of pipe –if not within the list of preferences-, has to be even more economic attractive than those projects that are considered elemental priority.

Figure 4.6. Socio-economic barriers: weight distribution based on interviewees criteria (normalized)

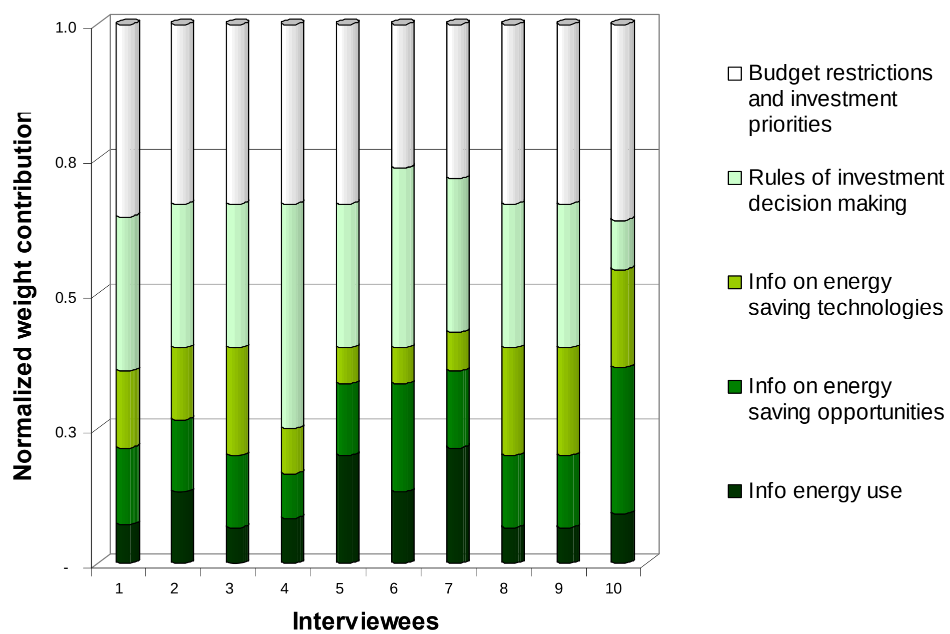
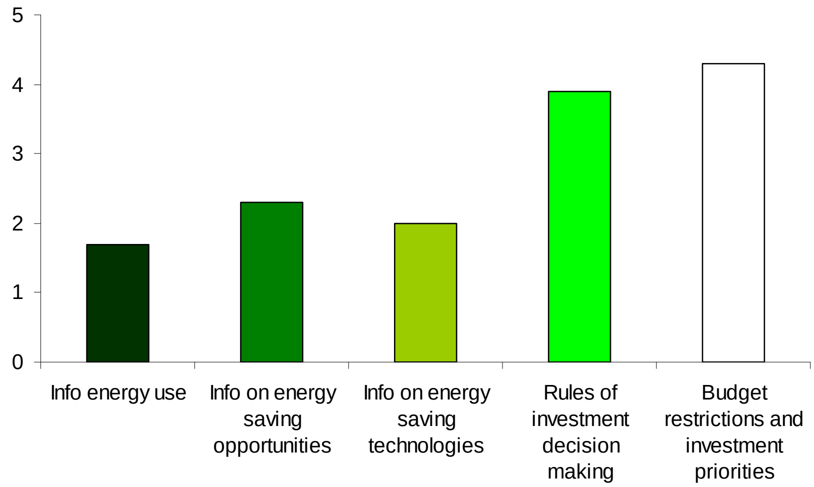


Figure 4.7. Socioeconomic cluster: average scores for barriers

(Max. score=5)



4.8 Technological barriers inside the IChem-NL

Regarding technological barriers to investments in energy savings, the energy intensive IChem-NL makes no clear distinction about what difficulty plays the main role in investment decision making [Figure 4.8]. Nonetheless, under BAU conditions, it is probable that the main obstacles are related to the technology fitting (score 3.7), loss of economic benefits (score 3.6) and technology investment irreversibility (score 3.1) [Figure 4.9]. Concerning the first one, due to the high complexity of chemical processes and their multi-productive nature[94], it is feared that changes in lay-outs due to technology retrofit could arise risk of loosing flexibility in

[94] Commonly at industrial scale, chemical processes are not output exclusive. Instead, it is usual that one chemical process produces more than one economic valuable chemical product.

feedstocks, processing, and products. Besides, the implementation of retrofit options is also constrained by physical limitations in plants[95].

Figure 4.8. Technological barriers: weight distribution based on interviewees criteria (normalized)

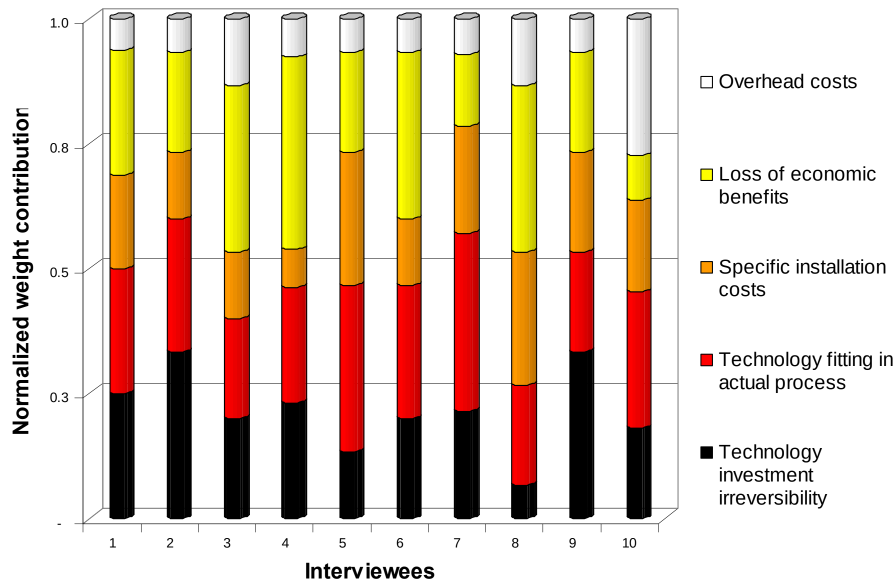
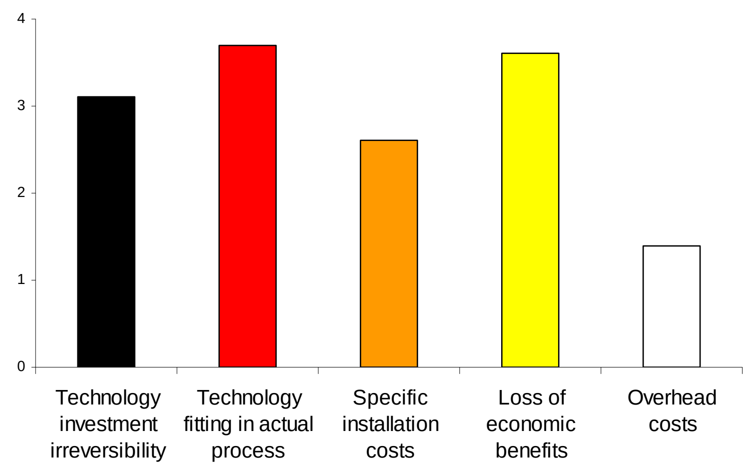


Figure 4.9. Technological cluster: average scores for barriers (Max. score =5)



[95] Many of the chemical plants in the Netherlands are over 30 years old. During that time, it could be the case that retrofitting, process improvement and capacity increase has diminished the availability of free space in production sites. Besides, even more realistic, it would be fair to assume that chemical plants were designed originally on a basis of spatial efficiency in order to reduce construction costs (e.g. the more spread processes are, the more costly it will be to set pipes, to distribute power and to transport products); costs of building up a chemical facility are kept to an optimal level by default.

Besides the previous barrier, there is also concern about the loss of benefits that could occur as a result of major technological retrofit. In addition to the cost involved in shutting down operations for equipment installation, the risk for later process disruptions due to inadequate operation or incompatibility of new equipments (viz. learning effect) causes enough disbelief to operators to discard innovation in layouts. This is understandable if, on top of that, the fact that any shortcoming in process manufacturing may have further consequences; the chemical industry in the Netherlands is rather complex and interlinked, any operational incident in one site could have imminent impacts over the processing of many others.

Finally, concerning the investment irreversibility of energy efficient technologies, it is possible that the energy intensive industry in the Netherlands is skeptic about the technological benefits that new energy saving equipment could bring along. In fact, given the failure to realistically measure the long term performance of energy efficient technologies (for instance, due to unavailability of large-scale proven benefits), firms valuate highly to keep operating with the type of technology is already known, even at short term costs. In other words, firms are unwilling to use a technology of which they are unaware or that they do not fully understand.

4.9 Lack of commitment: another obstacle to energy efficiency improvement

One major barrier that was discussed during interviews was related to the lack of commitment on energy matters at institutional level. For example, among political authorities, there is not definitive certainty about the role of energy policy in the long term; especially, regarding policy instruments applicable to the industry such as mandatory emission targets, financial incentives or taxes. Surely, at company level, there is not only distrust about the continuity of policy instruments (viz. whether they will be in place or not), but also there is uncertainty about the timeframe of their existence (e.g. for how long subsidies might be in place), their overlap with other policy instruments (e.g. divergence between national and European level energy and climate policies) or their cost effectiveness (e.g. decrease of industry energy consumption not because of energy efficiency improvement but because decreasing capacity of plants due to economic unsustainability). In this context, lack of commitment refers to the incapability of the government to ensure companies a long termed, cost-effective and consistent energy and climate policy framework. To some extent, this can be explained by the discontinuity of governance priorities between incoming and outgoing governments.

On the other hand, among companies there is good information about energy consumption at process level (e.g. chemical industry benchmarkings), even though it is not always presented clearly or consistently[96]. In many cases, this shortcoming leads to an under/overestimation of energy use, and further misunderstandings about allocation of energy utilization (viz. boundaries of the energy system) at higher levels e.g. government level. Then, lack of quality in reporting specific energy use (viz. at process or company level), leads to inconsistency with the monitoring of energy use at higher levels (e.g. sector or national level.); for instance, regarding energy statistics and energy use projections at country level. So, in this context, lack of commitment refers to the incapability of companies to ensure to the government consistent and detailed information about energy use[97].

4.10 Effectiveness of policy instruments on investment decision making in the IChem-NL

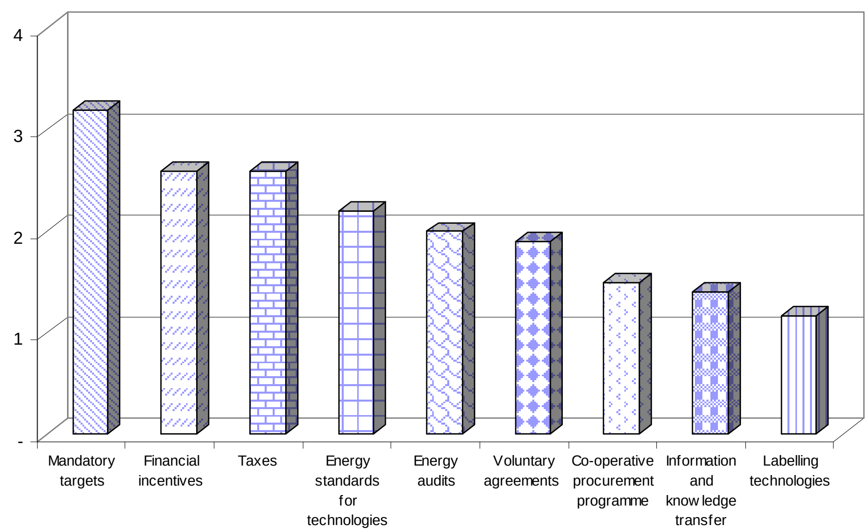
As part of this research, from a qualitative perspective, it was analyzed how firms increase energy efficiency in response to policy instruments. The outcomes derived from this assessment [Figure 4.10] suggest that mandatory targets (e.g. cap on CO_2 emissions), financial incentives (e.g. subsidies in energy saving technologies) and taxes (e.g. taxes on energy use) are possibly the more effective instruments. To illustrate this, command and control as well as market oriented policies are the most likely measures to positively influence the development of further energy

[96] In the Netherlands, proper monitoring of energy consumption in the industrial sector has been reported as irregular by different studies (Neelis, Pouwelse 2008, Neelis et al. 2007, Farla, Blok 2002). For the chemical industry, Neelis and Pouwelse (2008) suggested as major caveats: (1) inconsistency in system boundaries and (2) lack of guidance in complex energy conversions.

[97] To some extent, this can be explained by the confidentiality of energy use information due to the fear of loosing competitiveness advantages in the market.

efficiency improvement –at least, from firms' view-. Whereas mandatory targets touch directly one of the main drivers of firms to invest (viz. legal compliance), subsidies and taxes represent ways of reducing costs (viz. investment costs, in the case of subsidies; utility costs, in the case of taxes). Then, as a direct regulation or as a market oriented institution, these instruments are likely to be acknowledged in the energy intensive IChem-NL as effective in influencing project appraisals (especially, projects related to energy savings).

Figure 4.10. Effectiveness of policy instruments on investment decision making



4.11 Characterization of energy efficiency potential in the energy intensive IChem-NL

In this chapter, barriers to investment in energy savings in the IChem-NL are proposed and discussed[98]. Based on the outcome of the previous sections, the results showed a slight tendency for some barriers to be considered as more influential over energy saving investment decision making. For instance, based on average weights and scores of barriers within the different clusters, leading obstacles chosen by respondents were: A) change in energy prices (economic cluster); B) budget restrictions and other investment priorities (socioeconomic cluster); and, C) technology fitting in actual processes (technological cluster). Other barriers considered relevant were: a) economic trend and market situation; b) rules of investment decision making; c) loss of economic benefits; and, d) technology investment irreversibility. Finally, although not as part of the quantitative analysis, interviews revealed that lack of transparency is another significant barrier to consider [Table 4.2]. It is important to emphasize that this research exclusively considered barriers that could be attributed to economic or behavioral failures (Sorrell et al. 1999). Certainly, this decision was made in order to limit the extent of this research to barriers that could be ameliorated by policy intervention (as it will be explained in short) [99]. However, it would be unrealistic to think that other barriers, different to those proposed, are not present in

[98] Based on this analysis, the second research question of this study was partially answered.

[99] To justify this, it was assumed that given the size (i.e. global companies), market hierarchy (i.e. world chemical majors) and energy intensity (i.e. large consumers of energy) of the companies included in this study, organizational barriers related to energy saving investments (e.g. low status of energy management or lack of environmental values regarding energy use) were not present at a significant level.

the energy intensive IChem-NL e.g. organizational barriers such as company structure or culture (de Canio 1998, Velthuijsen 1993).

Barriers to investment in energy savings cannot be considered as independent or exclusive. Indeed, most of them interact in conjunction with energy efficiency investment decision making, influencing it and stopping it from realizing its maximum potential. From an economic perspective, these barriers explain the origins of the so called energy efficiency gap. In this context, the energy efficiency gap refers to the breach between real energy use and optimal energy use; in other words, the real energy efficiency and the potential energy efficiency. According to Jaffe and Stavins (1994a), within this gap different notions of economic potential[100] and distinct notions of social optimum[101] can be distinguished. Using these concepts, the results achieved in this research can be further contextualized. For instance, the energy efficiency potential that the energy intensive IChem-NL can achieve can only be reached by surpassing barriers that halt economic, socioeconomic and technological potentials; and only to the extent of which a distinct social optimum is realized by cost-benefit effective policy intervention [Figure 4.11]. In this way, the more barriers are removed, the higher the energy efficiency will be (i.e. the shorter the energy efficiency gap), but only to the level by which government programs are still cost-benefit effective.

[100] By economic potential, it is meant the degree of energy efficiency that would be achieved if various economic barriers were removed.
[101] By social optimum, it is meant the degree of energy efficiency achieved by instituting programs to encourage energy efficiency that are cost-benefit effective.

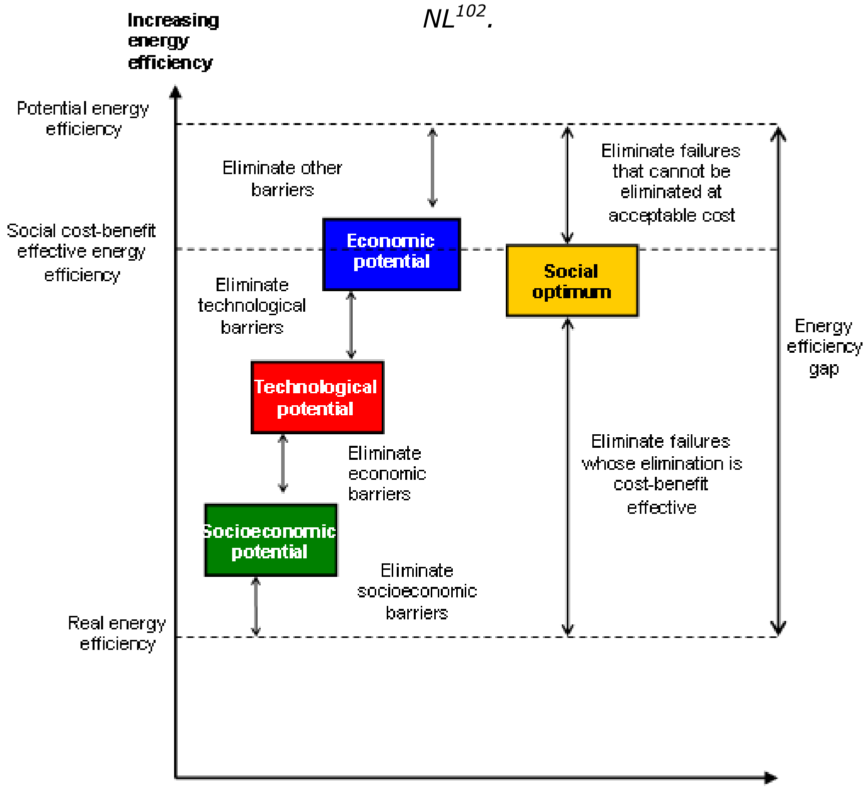
Cluster	Barrier	Main manifestation(s)
Economic	Change in energy prices	*Uncertainty about economic benefits of energy efficiency improvement (e.g. low price of energy).*
	Economic trend and market situation	*Fear to loose competitiveness in stagnating markets (e.g."unrecoverability" of investments).*
Socioeconomic	Budget restrictions and investment priorities	*Preference to invest in projects that brings along other benefits on top on energy efficiency (e.g. safety, legal compliance, increase in capacity, etc).*
	Rules of investment decision making	*Not enough economic attractiveness of exclusively related energy efficiency investments (i.e. energy efficiency does not pay well enough).*
Technological	Fitting in actual process	*Fear of loosing flexibility in processes; Unavailability of free space for further technology retrofitting.*
	Loss of economic benefits	*Fear to economic consequences due to plant operation disruption (e.g. major stop plant).*
	Technology investment irreversibility	*Fear to implement a technology that it is not known or fully understand at real process scale.*
Other	Lack of commitment on energy matters	*Lack of continuity of policy instruments (e.g. validity of subsidies); Lack of clear and detailed information on energy use at process, company, sector and sector level (e.g. inaccuracies within energy statistics and energy use projections)*

Table 4.2. Summary of barriers to investment in energy saving technology in the energy intensive IChem-NL as found in this study.

Reaching the social optimum would require a comprehensive set of measures including policy instruments such as mandatory targets, financial incentives, and taxes. As reviewed in this study, these would be probably the most effective in boosting further investments in energy efficiency. Nonetheless, it is worth mentioning that such energy efficiency optimum cannot be reached only by instituting such instruments, but by integrating them into a holistic policy strategy. Then, elements of a roadmap leading to improve energy efficiency in the energy intensive

IChem-NL must include a more innovative and multifaceted way of energy governance.

Figure 4.11. The energy efficiency gap of the energy intensive IChem-NL[102].



Based on (Jaffe, Stavins 1994a)

[102] In the figure, levels of efficiency are arbitrarily estimated (viz. distance of arrows between potentials do not necessarily represent the real impact of a set of barriers over energy efficiency). Besides, the order of potentials is also arbitrary. Moreover, the localization of the social optimum within the graph does not necessarily represent its real level (it is guessed that the cumulative impact of overcoming barriers with policy intervention will be restricted to a level lower than the potential energy efficiency). Finally, the difference in magnitudes between real energy efficiency and potential energy efficiency are symbolical (in reality, it would be expected that the energy efficiency gap was shorter). Figure 4.7 should only be used as a graphical representation of the influence of barriers and policy intervention over energy efficiency.

V. Industrial energy efficiency look ahead: conclusions

The objective of this research was to present general potentials and main obstacles to increase energy efficiency in the energy intensive IChem-NL. Firstly, energy saving measures and technologies that can be applied at processes level were identified and reviewed techno-economically. From this assessment, it was concluded that further energy savings can be achievable, at an economically attractive cost. In the manufacturing of ethylene, chlorine and PE, this could be realized by retrofitting specific technological improvements in processing (including process intensification), upgrading process control, and increasing heat recovery. Besides, it was showed, from a NPV perspective, that economic benefits of capturing such potential could triplicate total upfront investment costs from 2010 to 2020.

Finally, through and empirical evaluation, different economic, socioeconomic and technological barriers preventing investments in energy efficiency from taking place in the energy intensive IChem-NL were reviewed. It was concluded that no single barrier can be identified as the main cause of the diminishing of investments in energy efficiency. On the contrary, it is more likely to consider a cumulative impact of the interrelation of such barriers as the reason for a lack of investments in energy savings. Nonetheless, considering BAU conditions, it was concluded that there is a slight tendency for some barriers to be considered as more influential to energy saving investment decision making. Among them, changes in energy prices, budget restrictions and other investment priorities, and technology fitting in actual processes as well as lack of commitment might be highlighted.

It is expected that the conclusions achieved in this research have significance for energy and climate policy and modeling (e.g. energy use projections for the chemical industry in the Netherlands). Indeed, the overview projected in this study supports the argument that the energy intensive IChem-NL can make cost-effective energy efficiency improvements by overcoming barriers to investments when effective policy instrumentation is applied. Then, the findings of this research suggest that in order to achieve optimum energy efficiency level, it is a prerequisite to develop and perform a holistic policy strategy that focuses on the removal of the most influential barriers diminishing investments in energy savings.

This work could usefully be extended in a number of ways. First, a more extended review of energy saving measures and technologies (especially regarding process intensification options) for the processes studied would give a more accurate perspective of the real potential for energy efficiency improvement in the energy intensive IChem-NL. In addition, analyzing in detail the possibilities for their implementation at company level would also help to explain in higher detail obstacles faced by individual firms to improve energy use consumption.

Second, evaluating the concrete effects of economic, socioeconomic and technological barriers on the size of the energy efficiency gap would give a clearer perspective about the magnitude of the impacts of such barriers over energy efficiency investment decision making[103]. On top of that, it is also estimated that an extended analysis of the dynamics held among different barriers would also explain better the interconnectivity of such and the resulted cumulative impact over energy exclusive investments.

Finally, specific research about the practical implementation and ex post evaluation of energy and climate policies in the Netherlands could give stronger background for the formulation of a holistic policy strategy as proposed in this study. For instance, regarding the valuation of costs and benefits of energy and climate policy, and the assessment of the use of market based instruments for energy and climate (e.g. environmental bonds).

[103] A pioneer study in this field is the work done by (IEA 2007a). In the report "Mind the gap-Quantifying Principal-Agent Problems in Energy Efficiency", a first attempt to estimate the size of barriers to investment in energy efficiency is performed. Yet, the study focuses on the residential, commercial and end-user sector.

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Appendix A: fact sheets of measures

Naam van de maatregel	Advanced heat recovery measures	
(Sub)sector (SBI 2008)	24	
Energiefunctie of proces waarop de maatregel van toepassing is		
Besparing op het specifiek elektriciteitsverbruik van de energiefunctie (absoluut/relatief)		Bron: Martin et al. 2000, Emerging Energy-Efficient Industrial Technologies, Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, USA Onzekerheid [%]:
Besparing op het specifiek verbruik van warmte/brandstof van de energiefunctie (absoluut/relatief)	4% (Final Heat Use)	Bron: Martin et al. 2000, Emerging Energy-Efficient Industrial Technologies, Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, USA/ Expert opinion Onzekerheid [%]:
Soort maatregel (nieuw, retrofit, energiezorg)	Energy management	
Eerste jaar waarin de maatregel kan worden toegepast	2010	
Penetratiegraad van de maatregel (jaar)		Bron: Onzekerheid [%]:0
Technisch maximum voor de penetratiegraad van de maatregel		Bron: Onzekerheid [%]:100
Additionele investeringskosten (absoluut/relatief)	0.1 to 3.3 €/tonne$_{product}$	Bron: SC Oltchim 2000, Energy Audit at a Romanian Petrochemical Plant, EcoLinks, viewed January 20th 2010, http://archive.rec.org/ecolinks/bestpractices/PDF/romania_oltchim.pdf / Expert opinion Onzekerheid [%]:
Additionele beheer-en		Bron:

onderhoudskosten (absoluut/relatief)		Onzekerheid [%]:
Technische levensduur	10 years	Bron: Expert opinion Onzekerheid [%]:
Financieel voordeel (niet energie) (absoluut)		Bron: Onzekerheid [%]:
Overige informatie		

Financiële gegevens worden uitgedrukt in €$_{2009}$.

Naam van de maatregel	Process Control Sensors	
(Sub)sector (SBI 2008)	24	
Energiefunctie of proces waarop de maatregel van toepassing is		
Besparing op het specifiek elektriciteitsverbruik van de energiefunctie (absoluut/relatief)	3% (Based on final energy use per GJ/tonne $_{product}$)	Bron: Martin et al. 2000, Emerging Energy-Efficient Industrial Technologies, Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, USA/Expert opinion
Besparing op het specifiek verbruik van warmte/brandstof van de energiefunctie (absoluut/relatief)		Bron: Onzekerheid [%]:
Soort maatregel (nieuw, retrofit, energiezorg)	Retrofit	
Eerste jaar waarin de maatregel kan worden toegepast	2010	
Penetratiegraad van de maatregel (jaar)		Bron: Onzekerheid [%]: 0
Technisch maximum voor de penetratiegraad van de maatregel		Bron: Onzekerheid [%]: 100
Additionele	1 to 13	Bron: Martin et al. 2000, Emerging Energy-

investeringskosten (absoluut/relatief)	€/$tonne_{product}$	Efficient Industrial Technologies, Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, USA/Expert opinion Onzekerheid [%]:
Additionele beheer- en onderhoudskosten (absoluut/relatief)	10% investment cost	Bron: Expert opinion Onzekerheid [%]:
Technische levensduur		Bron: Onzekerheid [%]:
Financieel voordeel (niet energie) (absoluut)		Bron: Onzekerheid [%]:
Overige informatie		

Financiële gegevens worden uitgedrukt in $€_{2009}$.

Naam van de maatregel	Heat Integration Distillation Column (HIDiC)+Heat Pump	
(Sub)sector (SBI 2008)	24.14	
Energiefunctie of proces waarop de maatregel van toepassing is	Polyolefins (Ethylene from Steam cracking of naphtha)	
Besparing op het specifiek elektriciteitsverbruik van de energiefunctie (absoluut/relatief)		Onzekerheid [%]:
Besparing op het specifiek verbruik van warmte/brandstof van de energiefunctie (absoluut/relatief)	0.3 GJ_{Final}/tonne $product_{HIDiC}$+0.15 GJ_{Final}/tonne $product_{Heat\ pump}$=0.5 GJ_{Final}/tonne product	Bron: Ren, T 2008, Petrochemicals from Oil, Natural Gas, Coal and Biomass, Utrecht University / Expert opinion Onzekerheid [%]:
Soort maatregel (nieuw, retrofit, energiezorg)	Retrofit	
Eerste jaar waarin de maatregel kan worden toegepast	2010	
Penetratiegraad van de maatregel (jaar)		Bron: Onzekerheid [%]: 0
Technisch maximum voor de penetratiegraad van de maatregel		Bron: Onzekerheid [%]: 100
Additionele	7 €/$tonne_{ethylene}$	Bron: Nakaiwa, M,

investeringskosten (absoluut/relatief)		Huang, K, Endo, T, ohmori, T, Akiya, T & Takamatsu, T 2003, ' Internally heat-Integrated Distillation Columns: A Review', Chemical Engineering Research and Design, no. 81, pp. 162-177. / Expert opinion Onzekerheid [%]:
Additionele beheer- en onderhoudskosten (absoluut/relatief)	0.8 €/tonne$_{ethylene}$	Bron: Nakaiwa, M, Huang, K, Endo, T, ohmori, T, Akiya, T & Takamatsu, T 2003, ' Internally heat-Integrated Distillation Columns: A Review', Chemical Engineering Research and Design, no. 81, pp. 162-177. / Expert opinion Onzekerheid [%]:
Technische levensduur	20 years	Bron: Expert opinion Onzekerheid [%]:
Financieel voordeel (niet energie) (absoluut)		Bron: Onzekerheid [%]:
Overige informatie		

Financiële gegevens worden uitgedrukt in €$_{2009}$.

Naam van de maatregel	Gas turbine integration	
(Sub)sector (SBI 2008)	24.14	
Energiefunctie of proces waarop de maatregel van toepassing is	Polyolefins (Ethylene from Steam cracking of naphtha)	
Besparing op het specifiek elektriciteitsverbruik van de energiefunctie (absoluut/relatief)		Onzekerheid [%]:
Besparing op het specifiek verbruik van warmte/brandstof van de energiefunctie (absoluut/relatief)	3.4 GJ$_{Final}$/tonne product	Bron: Ren, T 2008, Petrochemicals from Oil, Natural Gas, Coal and Biomass, Utrecht University / Expert opinion Onzekerheid [%]:
Soort maatregel (nieuw, retrofit, energiezorg)	Retrofit	
Eerste jaar waarin de	2010	

maatregel kan worden toegepast		
Penetratiegraad van de maatregel (jaar)		Bron: Onzekerheid [%]: 0
Technisch maximum voor de penetratiegraad van de maatregel		Bron Onzekerheid [%]:100
Additionele investeringskosten (absoluut/relatief)	41 €/tonne$_{ethylene}$	Bron: Nakaiwa, M, Huang, K, Endo, T, ohmori, T, Akiya, T & Takamatsu, T 2003, ' Internally heat-Integrated Distillation Columns: A Review', Chemical Engineering Research and Design, no. 81, pp. 162-177. / Expert opinion Onzekerheid [%]:
Additionele beheer- en onderhoudskosten (absoluut/relatief)	19 €/tonne$_{ethylene}$	Bron: Nakaiwa, M, Huang, K, Endo, T, ohmori, T, Akiya, T & Takamatsu, T 2003, ' Internally heat-Integrated Distillation Columns: A Review', Chemical Engineering Research and Design, no. 81, pp. 162-177. / Expert opinion Onzekerheid [%]:
Technische levensduur	20 years	Bron: Expert opinion Onzekerheid [%]:
Financieel voordeel (niet energie) (absoluut)		Bron: Onzekerheid [%]:
Overige informatie		

Financiële gegevens worden uitgedrukt in €$_{2009}$.

Naam van de maatregel	Oxygen Depolarised Cathodes	
(Sub)sector (SBI 2008)	24.13	
Energiefunctie of proces waarop de maatregel van toepassing is	Chlorine (from HCl)	
Besparing op het specifiek elektriciteitsverbruik van de energiefunctie (absoluut/relatief)	33 % (Final Electricity Use base on 12 GJ/tonne $_{chlorine}$ and electricity share of 84%)	Bron: Moussallem, I, Jörissen, Ulrich Kunz, Pinnow, S & Turek, T 2008, 'Chlor-alkali electrolysis with oxygen

		depolarized cathodes: history, present status and future prospects', Journal Applied Electrochemistry, no.88, pp. 1177-1194. / Expert opinion Onzekerheid [%]:
Besparing op het specifiek verbruik van warmte/brandstof van de energiefunctie (absoluut/relatief)		Bron: Onzekerheid [%]:
Soort maatregel (nieuw, retrofit, energiezorg)	New	
Eerste jaar waarin de maatregel kan worden toegepast	2010	
Penetratiegraad van de maatregel (jaar)		Bron: Onzekerheid [%]: 0
Technisch maximum voor de penetratiegraad van de maatregel		Bron: Onzekerheid [%]: 100
Additionele investeringskosten (absoluut/relatief)	2.2 €/tonne$_{chlorine}$ (based on a two times break even cost of 750 $\$/m^2$)	Bron: Moussallem, I, Jörissen, Ulrich Kunz, Pinnow, S & Turek, T 2008, 'Chlor-alkali electrolysis with oxygen depolarized cathodes: history, present status and future prospects', Journal Applied Electrochemistry, no.88, pp. 1177-1194./ Expert opinion Onzekerheid [%]:
Additionele beheer- en onderhoudskosten (absoluut/relatief)		Bron: / Expert opinion Onzekerheid [%]:
Technische levensduur	400 days of continuous operation (change of cathodes)	Bron: Morimoto T, suzuki K, Matsubara T & Yoshida N 2000, 'Oxygen reduction electrode in brine electrolysis', *Electrochimica Acta*, no.45, pp. 4257-4262. Onzekerheid [%]:
Financieel voordeel (niet energie) (absoluut)		Bron: Onzekerheid [%]:
Overige informatie		

Financiële gegevens worden uitgedrukt in €$_{2009}$.

Naam van de maatregel	Static Mixers	
(Sub)sector (SBI 2008)	24.11, 24.12, 24.16, 24.17	
Energiefunctie of proces waarop de maatregel van toepassing is	Polyethylene (e.g. HDPE and LDPE)	
Besparing op het specifiek elektriciteitsverbruik van de energiefunctie (absoluut/relatief)	In HDPE: 2% in process+ 6% in extrusion (with gear pumps); final energy use base on 2.05 GJ/tonne $_{HDPE}$. In LDPE: 13% in process +11% in extrusion (with gear pumps); final energy use base on 2.59 GJ/tonne $_{LDPE}$.	Bron: European Roadmap of Process Intensification – static Mixers, Technology Report./ Rosato, D.V. 1998, Extruding Plastics, 1st edn, Kluwer Academic Publishers, Norwell, Massachusetts./ Expert opinion Onzekerheid [%]:
Besparing op het specifiek verbruik van warmte/brandstof van de energiefunctie (absoluut/relatief)	In HDPE: 26% in heat transfer (steam); final energy use base on 2.05 GJ/tonne $_{HDPE}$.	Bron: European Roadmap of Process Intensification – static Mixers, Technology Report./ Rosato, D.V. 1998, Extruding Plastics, 1st edn, Kluwer Academic Publishers, Norwell, Massachusetts./ Expert opinion Onzekerheid [%]:
Soort maatregel (nieuw, retrofit, energiezorg)	New	
Eerste jaar waarin de maatregel kan worden toegepast	2010	
Penetratiegraad van de maatregel (jaar)		Bron: Onzekerheid [%]: 0
Technisch maximum voor de penetratiegraad van de maatregel		Bron: Onzekerheid [%]: 100
Additionele investeringskosten (absoluut/relatief)	0.3 to 0.5 €/tonne$_{polyethylene}$	Bron: European Roadmap of Process Intensification – static Mixers, Technology Report../ Expert opinion Onzekerheid [%]:
Additionele beheer- en onderhoudskosten	10% investment cost	Bron: European Roadmap of Process Intensification – static Mixers, Technology Report../

(absoluut/relatief)		Expert opinion Onzekerheid [%]:
Technische levensduur	20 years	Bron: Expert opinion Onzekerheid [%]:
Financieel voordeel (niet energie) (absoluut)		Bron: Onzekerheid [%]:
Overige informatie		

Financiële gegevens worden uitgedrukt in $€_{2009}$.

Appendix B: economic assessment of measures

	Measure	Investment costs (M€$_{2009}$)	O&M costs (M€$_{2009}$)	α	Annual benefits from savings (M€$_{2009}$)	PBT	Annualized measure cost (M€$_{2009}$)	Units energy saved (PJ)	COE (€/GJ)
Ethylene (based on a facility of 500 ktonnes/year)	Heat Recovery	1.6	-	15%	5.5	<1	0.3	0.5	0.5
	Heat Integrated Distillation Column (HIDiC)+Heat Pump	3.5	0.4	10%	2.3	2	0.8	0.2	3.4
	Process Control Sensors	6.4	0.6	15%	4.3	<2	1.6	0.4	3.9
	Gas Turbines	20.4	9.4	9%	17.4	3	11.2	1.7	6.7
Chlorine (based on a facility of 400 ktonnes/year)	Heat Recovery	0.1	-	15%	0.3	<1	0.0	0.0	0.5
	Oxygen depolarized cathodes	0.9	0.0	99%	29.1	<1	0.9	1.2	0.7
	Process Control Sensors	2.0	0.2	15%	3.0	1	0.5	0.1	3.9
LDPE (based on a facility 300 ktonnes/year)	Static Mixers	0.1	0.0	15%	4.7	<1	0.0	0.2	0.1
	Process Control Sensors	0.3	0.0	15%	0.5	1	0.1	0.0	4.0
HDPE (based on a facility 320 ktonne/year)	Static Mixers	0.2	0.0	15%	3.2	<1	0.0	0.2	0.2
	Heat Recovery	0.0	-	15%	0.1	<1	0.0	0.0	0.5
	Process Control Sensors	0.3	0.0	15%	0.3	1	0.1	0.0	3.9

Appendix C: matrix of results (pair wise comparison of barriers and policy instruments) [A]

Potential	Economic Potential				Socioeconomic Potential				
BIEST's / Firm	Availability external and internal capital	Change in energy prices	Economic trend and market situation	Discontinuation economic policy instruments	Info energy use	Info on energy saving opportunities	Info on energy saving technologies	Rules of investment decision making	Budget restrictions and investment priorities
1	0.13	0.38	0.13	0.38	0.07	0.14	0.14	0.29	0.36
2	0.10	0.30	0.40	0.20	0.13	0.13	0.13	0.27	0.33
3	0.40	0.30	0.20	0.10	0.07	0.13	0.20	0.27	0.33
4	0.10	0.30	0.40	0.20	0.08	0.08	0.08	0.42	0.33
5	0.30	0.40	0.20	0.10	0.20	0.13	0.07	0.27	0.33
6	0.30	0.10	0.20	0.40	0.13	0.20	0.07	0.33	0.27
7	0.30	0.30	0.10	0.30	0.21	0.14	0.07	0.29	0.29
8	0.20	0.40	0.30	0.10	0.07	0.13	0.20	0.27	0.33
9	0.30	0.20	0.40	0.10	0.07	0.13	0.20	0.27	0.33
10	0.30	0.40	0.20	0.10	0.09	0.27	0.18	0.09	0.36

[A] Scores given by interviewees to different barriers and instruments; level of influence over investment decision making in energy efficiency according to respondents opinion.

Potential	Technological Potential				
BIEST's / **Firm**	Technology investment irreversibility	Technology fitting in actual process	Specific installation costs	Loss of economic benefits	Overhead costs
1	0.25	0.25	0.19	0.25	0.06
2	0.33	0.27	0.13	0.20	0.07
3	0.20	0.20	0.13	0.33	0.13
4	0.23	0.23	0.08	0.38	0.08
5	0.13	0.33	0.27	0.20	0.07
6	0.20	0.27	0.13	0.33	0.07
7	0.21	0.36	0.21	0.14	0.07
8	0.07	0.20	0.27	0.33	0.13
9	0.33	0.20	0.20	0.20	0.07
10	0.18	0.27	0.18	0.09	0.27

	Regulation			**Financial**		**Information**		**Voluntary Agreements**	**Procurement**
Policy Instrument / **Firm**	*Energy performance standards for industrial technologies*	*Mandatory targets/tradable certificates for (demand-side) energy savings for energy companies.*	*Labeling of industrial technologies*	*Financial/fiscal instruments such as soft loans, subsidy schemes, investment deduction schemes, rebates.*	*Energy tax/ energy tax exemption.*	*Information/ knowledge transfer/ education/ training.*	*Energy audits.*	*Voluntary agreements to save energy or improve energy efficiency.*	*Co-operative procurement programme.*
1	2	2	2	2	2	2	2	2	2
2	3	4	2	1	2	2	3	3	-
3	3	4	1	3	3	-	-	2	2
4	1	3	1	4	3	1	2	3	2
5	3	4	1	3	3	2	2	1	2
6	3	4	-	4	4	2	4	1	2
7	1	3	NA	3	3	2	1	2	1
8	3	3	NA	2	-	2	3	2	1
9	1	2	NA	2	3	-	1	1	NA
10	2	3	NA	2	3	1	2	2	NA

Appendix D: survey questionnaire

I Energy Performance

1. Your company and its business

1.1 What is the name of your company?

……………………………………..

1.2 Where is your production site located?

……………………………………..

1.3 What chemical industry category would define better your production site : (multiple answers possible)

- O Lower Olefins viz. ethylene production
- O Chlor-Alkali viz. chlorine production
- O Polyolefins A viz. HDPE production
- O Polyolefins B viz. LDPE production

- O Other; Please mention:………………………………..

1.4 Is your production site part of a larger group?

- O Yes, because (multiple answers possible):
  - o There are several locations in the Netherlands.
  - o There are other locations abroad.
- O No

1.5 Which activities are you personally involved in (multiple answers possible):

- O Financial management
- O Technical management
- O Energy management
- O Production management
- O Public relations
- O Investment management
- O General management
- O Research and development
- O Other, namely……………….

1.6 What is the nature of your duties and responsibilities (multiple answers possible):

- O Advisory
- O Executive
- O Jurisdiction

1.7 What is the total production capacity of your production site?

	Amount	Units/year
Product 1	…………..	…………..
Product 2	…………..	…………..
Product 3	…………..	…………..
Product 4	…………..	…………..

1.8 What was in 2008 (or last financial year) the total production of your production site.

	Amount	Units
Product 1	…………..	…………..
Product 2	…………..	…………..
Product 3	…………..	…………..
Product 4	…………..	…………..

1.9 Please indicate how relevant the following goals are for making investment decisions in your production site:

	Totally unimportant	Unimportant	Relatively important	Important	Very Important
National sales increase					
International sales increase					
Profit increase in the short term (e.g. expansion)					
Long term returns					
Increase labor productivity					

Efficient production increase in processes					
Product innovation					
Lowering energy costs (e.g. higher yields)					
Improve environmental image					
Other:……….					
Other:……….					

2. Your energy system

2.1 Does your plant have a separate energy manager or energy management department?

- O Yes………..person(s) on the basis of …………man hours per week.
- O No

2.2 How old is your production site?

………..years

2.3 What was the breakdown of energy consumption in 2008 (or last financial year) in your production site?

	Amount	Units
Electricity		
Bought from grid	…………..	…………..
Generated on site for own use	…………..	…………..
Natural Gas	…………..	…………..
Fuels		
For energy	…………..	…………..
Feedstocks	…………..	…………..
Steam		
Bought from supplier	…………..	…………..
Generated on site for own use	…………..	…………..
Other	…………..	…………..

Note: If energy consumption breakdown unknown, please state estimated total energy use in production process (in GJ/tonne of product):.....................

2.4 Have you applied energy saving measures and technologies in the last 10 years? If so, which ones:

- O Yes
- O No

Crosscutting							
O	Heat recovery	O	Compressed air systems management	O	Switched reluctance drivers	O	Motor system optimization
O	Advanced adjustable speed drives designs	O	High technology in heating, ventilation and air conditioning equipment	O	Premium lubricants	O	Process control sensors
O	Advanced compressor controls	O	Pump system efficiency improvement	O	Advance lightning technology	O	Pinch analysis/ process integration

Process Specific				Utilities	
O	New catalysts	O	Gas membrane separation	O	Advanced CHP
O	High efficiency low Nox burners	O	Liquid membrane separation	O	Fuel cells
O	Cooling systems management	O	Fouling minimization	O	Advanced reciprocating engines

Others

a) ....

b) ....

c) ....

d) ....

e) ....

2.5 What was the main objective of the previous energy measures and technologies measures?

- O Sales increase
- O Profit increase short term

- Long term returns
- Increase productivity
- Product innovation
- Lowering energy costs
- Improve environmental image

2.6 Do you think there is further room for energy savings at your production site? If so, where?

- Yes, there is further room for energy savings at:

....

....

....

....

....

- No, there is further room for energy savings.

2.7 If the answer in 2.6 was "Yes", please indicate what could be the main reasons that explain why such room has not been filled in yet.

	Totally unimportant	Unimportant	Relatively Important	Important	Very Important
Lack of internal/external capital.					
Uncertain cost-benefit or profitability of savings due to uncertainty of energy prices or world economy.					
Lack of information regarding energy savings opportunities or/and technologies.					
Uncertain cost-benefit or profitability of savings due to business related factors (e.g. PBP, IRR, NPV)					

Budget restrictions or other investment priorities.					
Unreliable energy saving measures or/and technologies or they do not fit in actual process.					
There are important hidden costs (e.g. costs of production interruption, installation or information)					

2.8 What energy saving measures or technologies is your production site planning to apply in the next 10 years? Please describe:

a)..
....
....

b...
....
....

c...
....
....

2.9 What is the latest energy saving technology that was implemented in your production site?

a)...

b)...

c)...

O Do not know what the most recent applied energy saving technology is.

2.10 What is your top 3 main technology licensors?

1)..

2)..

3)..

2.11 What technologies (energy-efficient) were they providing?

1)..

2)..

3)..

II Investment Decision Making

1. Investments on energy savings

1.1 Can you estimate the magnitude of total investment of your production site in the following years?

2006............ a) M€'s b) M£'s c) MUSD's (choose one)

2007............ a) M€'s b) M£'s c) MUSD's (choose one)

2008............ a) M€'s b) M£'s c) MUSD's (choose one)

1.2 What was the main objective of such investments? (multiple answers possible)

- O Sales increase
- O Profit increase short term
- O Long term returns
- O Increase productivity
- O Product innovation
- O Lowering energy costs
- O Improve environmental image

1.3 Can you estimate the size of the investment that was purely aimed at improving energy efficiency of your production site in recent years? You can give absolute amounts, or shares if uncertain about absolute amounts.

2006............ a) M€'s b) M£'s c) MUSD's %.....of total investment

2007............ a) M€'s b) M£'s c) MUSD's %.....of total investment

2008............ a) M€'s b) M£'s c) MUSD's %.....of total investment

1.4 Can you estimate future investments that will be purely aimed at improving energy efficiency of your production site in the next 4 to 10 years? You can give absolute amounts, or shares if uncertain about absolute amounts.

In the next 4 years:

………… a) M€'s b) M£'s c) MUSD's %.....of total investment

In the next 10 years:

………… a) M€'s b) M£'s c) MUSD's %.....of total investment

1.5 What is the preferred financial parameter considered by your company when making energy related investments decisions? Please indicate an estimated value for it:

- O Simple Pay Back Period (PBP): …………
- O Net present Value (NPV): …………
- O Internal Rate of return (IRR): …………
- O Investment as a percentage of total plant investment: …………
- O Cost of energy saved (COE): …………

1.6 What are the most common values considered by your company when performing cost-benefit analysis? For:

Discount rate: …………

Depreciation period: …………

2. Barriers to investments on energy savings

2.1 Different studies suggest that current investment in energy savings in the chemical industry is not enough to achieve its maximum energy savings potential. Do you agree? If so, what are the main reasons that could explain it?

O Yes, I agree. The main reasons are:

a)………………………………………..

b)…………………………………………

c)…………………………………………..

O No, I do not agree.

Further comments:………………………………………………………………
…………………………………………………………………………………..
…………………………………………………………………………………..

2.2 In your opinion, how important the following potentials are when defining strategies to overcome barriers to investment in energy savings.

	Totally unimportant	Unimportant	Relatively Important	Important	Very Important
Economic Potential; mitigation options that eliminate market, public policies and institutional failures that inhibit the diffusion of energy saving technologies and measures.					
Socioeconomic: mitigation options that enhance individual and collective behavior viz. habits, attitudes and social norms and, vested interests towards the diffusion of energy saving technologies and measures.					
Technological: mitigation options that contribute to implementing already demonstrated energy saving technologies and measures.					

2.3 Please state what you consider more important between each of the pair of options:

Regarding economic barriers:

Option I	or		Option II
Availability of external or/and internal capital	O	O	Change in energy prices
Economic trend and market situation	O	O	Availability of external or/and internal capital
Availability of external or/and internal capital	O	O	Policy regulation
Change in energy prices	O	O	Economic trend and market situation
Policy regulation	O	O	Change in energy prices
Economic trend and market situation	O	O	Policy regulation

Regarding socio-economic barriers:

Option I	or		Option II
Lack of information on energy use	O	O	Lack of information regarding energy saving opportunities (e.g. measures)
Lack of information on energy saving new technologies	O	O	Lack of information on energy use
Lack of information on energy use	O	O	Investment decision making restricted to PBP, NPV, IRR, COE, etc
Budget restrictions and investment priorities	O	O	Lack of information on energy use
Lack of information regarding energy saving opportunities (e.g. measures)	O	O	Lack of information on energy saving new technologies
Investment decision making restricted to PBP, NPV, IRR, COE, etc	O	O	Lack of information regarding energy saving opportunities (e.g. measures)
Lack of information regarding energy saving opportunities (e.g. measures)	O	O	Budget restrictions and investment priorities
Investment decision making restricted to PBP, NPV, IRR, COE, etc	O	O	Lack of information on energy saving new technologies
Lack of information on energy saving new technologies	O	O	Budget restrictions and investment priorities
Budget restrictions and investment priorities	O	O	Investment decision making restricted to PBP, NPV, IRR, COE, etc

Regarding technological barriers:

Option I	or		Option II
Unreliability of technology	O	O	Fitting in actual process
Specific Installation Costs	O	O	Unreliability of technology
Unreliability of technology	O	O	Loss of Benefits
Overhead costs	O	O	Unreliability of technology
Fitting in actual process	O	O	Specific Installation Costs
Loss of Benefits	O	O	Fitting in actual process
Fitting in actual process	O	O	Overhead costs
Loss of Benefits	O	O	Specific Installation Costs
Specific Installation Costs	O	O	Overhead costs
Overhead costs	O	O	Loss of Benefits

III Policies for energy and climate

1. Policy instruments acceptability

1.1 It is estimated that current energy efficiency index (EEI)[A] in the Dutch industrial sector is around 0.79% p.a. In your opinion, what is the most adequate future scenario for the chemical industry?

- O the EEI will increase.
- O the EEI will remain constant.
- O the EEI will not decrease considerably.
- O the EEI will decrease considerably.

2.2 How influent would you define the following policy instruments with respect of the way you make your investment decisions?

[A] EEI is an indicator calculated by dividing realized energy use (from energy statistics) by a reference energy use (based on energy use in 1995). An EEI below 1 indicates that an industry has become more energy efficient compared to 1995 level; an EEI above 1 indicates that an industry has become less energy efficient compared to 1995 levels.

	Very unlikely to influence	Unlikely to influence	Reasonably likely to influence	Likely to influence	Very likely to influence
Energy performance standards for industrial technologies					
Mandatory targets/tradable certificates for (demand-side) energy savings.					
Labeling of industrial technologies.					
Financial/fiscal instruments such as soft loans, subsidy schemes, investment deduction schemes, rebates.					
Energy tax/ energy tax exemption.					
Information/ knowledge transfer/ education/ training.					
Energy audits.					
Voluntary agreements to save energy or improve energy efficiency.					
Co-operative procurement program.					