CENTRE FOR EUROPEAN POLICY STUDIES

Framework Contract

No ENTR/2008/006 Lot 4

for the Procurement of Studies and Other Supporting Services on Commission Impact Assessments and Evaluation

FINAL REPORT

For a study on composition and drivers of energy prices and costs in energy intensive industries: the case of the chemical industry - chlorine

Contractor
Centre for European Policy Studies

Prof. Christian Egenhofer & Dr. Lorna Schrefler (Team Leaders)

Vasileios Rizos
Federico Infelise
Dr. Giacomo Luchetta
Dr. Felice Simonelli
Wijnand Stoefs
Jacopo Timini
Lorenzo Colantoni

Done in Brussels, 13 January 2014

TABLE OF CONTENTS

1. Chlorine 1
   - 1.1 Chemical description and uses 1
   - 1.2 Chlorine market features 2
   - 1.3 Chlorine production technologies 4
   - 1.4 The Chlorine value chain 6
   - 1.5 The EU chlorine market 6
   - 1.6 Sample selection 8
     - 1.6.1 Sample selection criteria 8
     - 1.6.2 Sample statistics 8
   - 1.7 Methodology 9
     - 1.7.1 Data collection 9
     - 1.7.2 Data analysis and presentation 10
     - 1.7.3 Calculation of indirect ETS costs 12
     - 1.7.4 Validation of information 13
   - 1.8 Energy prices trends 13
     - 1.8.1 Introduction 13
     - 1.8.2 General trends 14
     - 1.8.3 Regional differences 15
   - 1.9 Analysis of energy bills components 16
     - 1.9.1 General trends 16
     - 1.9.2 Regional differences 18
   - 1.10 Energy intensity 19
     - 1.10.1 General trends 19
     - 1.10.2 Regional differences 20
   - 1.11 Indirect ETS costs 20
     - 1.11.1 Results 20
     - 1.11.2 Key findings 22
   - 1.12 Production costs 22
   - 1.13 General impressions 24

References 25

List of Figures and Tables

Figure 1. Uses of chlorine by sector, 2012 2
Figure 2. Chlorine world demand and construction spending, 1990-2013 3
Figure 3. Chlorine world production cost (membrane technology) by geographical area, 2012 3
Figure 4. World chlorine capacity by production technology, 2012 5
Figure 5. World number of plants and capacity using mercury cell technologies 5
Figure 6. Chlorine value chain 6
Figure 7. EU division in major geographical regions 11
Figure 8. Electricity prices paid by EU chlorine producers, (€/MWh) 14
Figure 9. Electricity prices paid by EU chlorine producers (box plots), (€/MWh) 15
Figure 10. Regional gaps of electricity price with EU average, (€/MWh) 16
Figure 11. Components of the electricity bill paid by EU chlorine producers (€/MWh) 17
Figure 12. Components of the electricity bill paid by EU chlorine producers (in %) 18
Figure 13. Electricity intensity of EU chlorine producers (MWh/tonne) 20
Figure 14. Total production costs of EU chlorine producers (€/tonne) 24

Table 1. Uses of Chlorine 1
Table 2. EU-27 capacity and number of plants per country, 2013 7
Table 3. EU-27 capacity of chlorine per technology, 2013 7
Table 4. EU-27 chlorine plants statistics, 2013 9
Table 5. Chlorine plants sample statistics 9
Table 6. Chlorine plants sample statistics on production technologies 9
Table 7. Number of questionnaires received and used in each section 10
Table 8. Average yearly prices per tonne of CO_2 (€) 13
Table 9. Share of electricity in total energy costs and total production costs 14
Table 10. Descriptive statistics for electricity prices paid by sampled EU chlorine producers (€/MWh) 15
Table 11. Chlorine indirect costs, averages per region (Euro/tonne of chlorine) 21
Table 12. Chlorine indirect costs, averages per region (Euro/tonne of chlorine) 21
Table 13. Chlorine indirect costs, averages per region (Euro/tonne of chlorine) 21
Table 14. Production costs of EU chlorine producers 23

1. Chlorine

1.1 Chemical description and uses

Chlorine (Cl) is a chemical element that, under standard conditions, appears as a greenish-yellow gas formed by diatomic molecules (Cl_2).

Chlorine is one of the most common elements in nature but, due to its high reactivity, it practically does not exist by itself and is usually found bound with other elements. Common kitchen salt (sodium chloride) is probably the best example of inorganic chlorinated substances while the oceans, forest fires and fungal activity are examples of organic chlorinated substances.

The production of chlorine is one of the major sectors within the global chemical industry. According to the World Chlorine Council (2012), the annual global production capacity of chlorine is estimated at around 60 million metric tonnes.

Chlorine was discovered in 1774 by the Swedish chemist Karl Wilhelm Scheele; until the beginning of the 21st century it had been used mainly for its sanitation properties in different scientific health-related fields ranging from the disinfection of household water supply to the development of improved medications. The invention of polyvinyl chloride (PVC) in 1912 was a major breakthrough for the large-scale industrial production of chlorine. Nowadays, chlorine plays a key role in many industries, as illustrated in the table below.

Table 1. Uses of Chlorine[1]

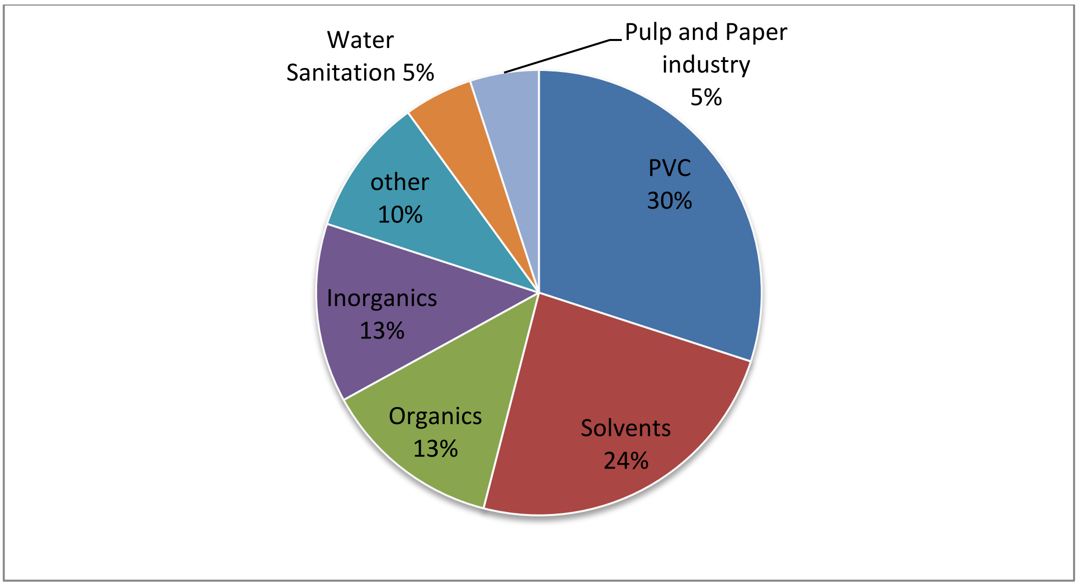
Industry	Application
Pulp and paper industry	Chlorine and its compounds are used to bleach wood pulp during the paper production process.
Manufacture of organic chemicals	Chlorine is used for making ethylene dichloride, glycerine, glycols, chlorinated solvents and chlorinated methanes.
Plastic industry	Chlorine is used for making plastics, most notably polyvinyl chloride (PVC), which is being used extensively in building and construction, packaging, and many other items.
Pesticides	96 % of all pesticides are produced using chlorine.
Industrial solvents	A variety of chlorinated compounds are used as industrial solvents, including the main ingredient used in dry cleaning.
Water treatment	Chlorine is used in 98 % of the water treatment plants in the world.
Pharmaceuticals	85 % of all pharmaceuticals use chlorine at some point in the production process.
Other relevant applications	Domestic bleaches, flame-retardants, food additives, refrigerants, insulation, computer chip manufacturing and hospital disinfectants among others.

[1] The source of the major uses of chlorine is the website of the Centre for Science and Environment, available at: http://www.cseindia.org/node/283; accessed: 30 October 2013.

1.2 Chlorine market features

As shown in Figure 1, chlorine has a very broad set of applications. The PVC industry accounts for 30% of the total chlorine demand and, due to its multiple different uses within cornerstone sectors such as construction, automotive, IT and packaging, it is often seen as the key driver of the global demand for chlorine.

Figure 1. Uses of chlorine by sector, 2012



Source: Authors' elaboration on Greener-industry (2012).

The exposure of the chlorine industry to sectors whose expansion is highly correlated to the level of the general economic activity makes the demand for chlorine highly pro-cyclical. Since 1990, despite some low-demand periods around the major episodes of strong global economic downturn (notably in early 2000 and between 2007-2009), global demand for chlorine has been steadily growing (see Figure 2) and, in the period 1990-2012, it experienced an annual average growth rate of 2.4%.

Producing chlorine is an energy-intensive activity. The key input for the production process, irrespective of the specific technology applied in each plant, is electricity[2]. As a result, electricity is a key cost driver for the chlorine industry as it accounts for approximately 50%[3] of the total cash production cost[4] (Eurochlor, 2010). Both physically and chemically, the electric current is essential to the chlor-alkali reaction and there are virtually no viable options to produce chlorine on an industrial scale without recurring to electricity. Figure 3 highlights the key role of electricity costs in driving the total cost of

---

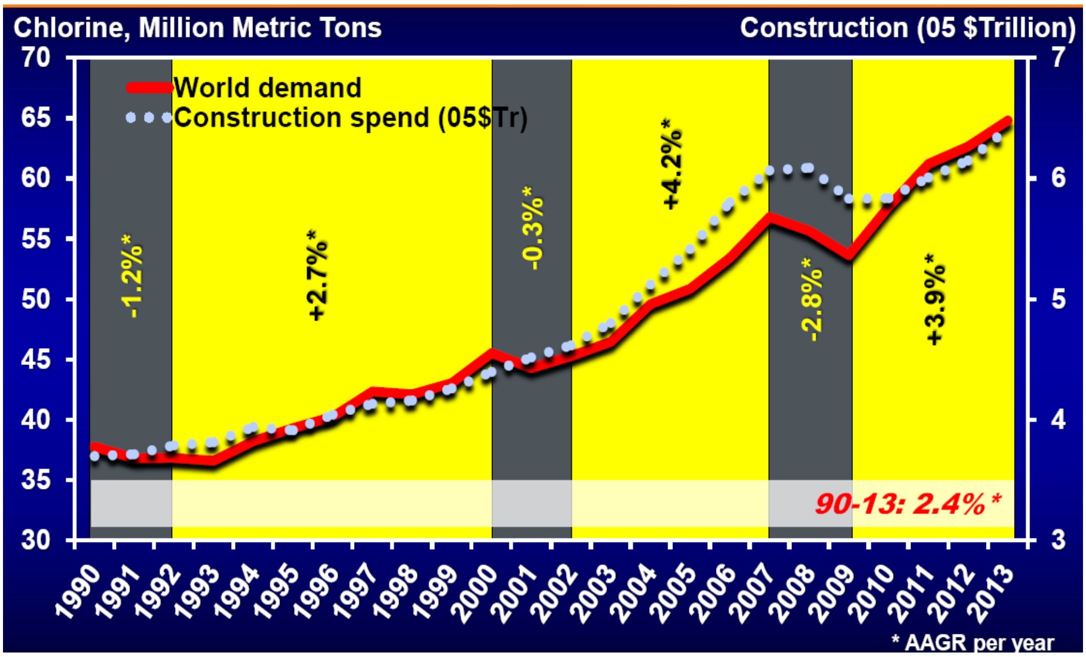
[2] Around 90% of the total electricity used for chlorine electrolysis is used as raw material, while the remaining 10% is used for lighting and operating pumps, compressors and other necessary equipment (Eurochlor, 2010).

[3] It should be emphasised that this figure presents a broad estimate for the chlorine industry, as there are large variations in the capacities of EU plants as well as in the technologies used for chlorine production.

[4] The total production cost refers to the sum of the cost of raw materials, labour cost, maintenance costs, overhead costs and taxes.

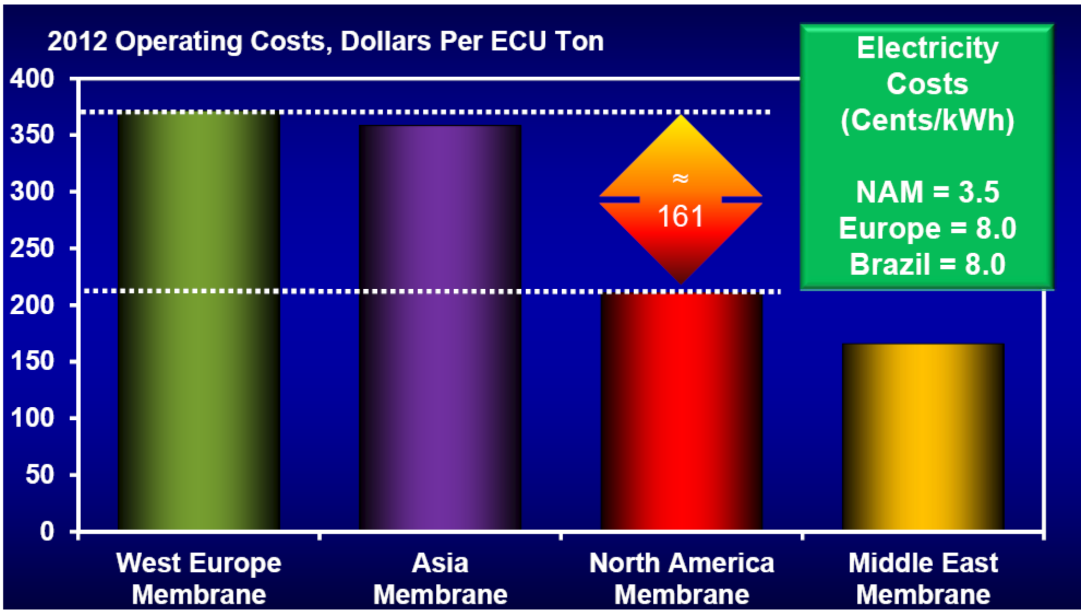
chlorine production and ultimately in shaping the international competitiveness of different geographical areas. According to IHS (2013), the electricity price differential between North America and Western Europe, which is in the range of 4.5 USD cents per kW/h, is the key factor in determining a price differential among the two regions of roughly 161 USD per ton of electrochemical unit (ECU)[5].

Figure 2. Chlorine world demand and construction spending, 1990-2013



Source: IHS (2013).

Figure 3. Chlorine world production cost (membrane technology) by geographical area, 2012



Source: IHS (2013).

---

[5] The electrolysis of brine produces a fixed ratio of 1 tonne of chlorine, 1.1 tonne of caustic soda and 0.03 tonne of hydrogen; this product combination is called Electrochemical Unit (ECU).

1.3 Chlorine production technologies

At industrial level, virtually all chlorine is produced by passing electricity through a solution of brine, which is common salt dissolved in water. This process is called electrolysis. The chemical reaction generated by the electrolysis of the three raw materials at the base of this process (namely salt, water and electricity) generates chlorine and also two other co-products: *caustic soda* (sodium hydroxide or NaOH) and *hydrogen* (H_2) Both caustic soda and hydrogen have important applications in other industrial sectors[6] since, despite their high reactivity, the development of efficient technologies has enabled the separation of these three substances allowing their use in further industrial processing.

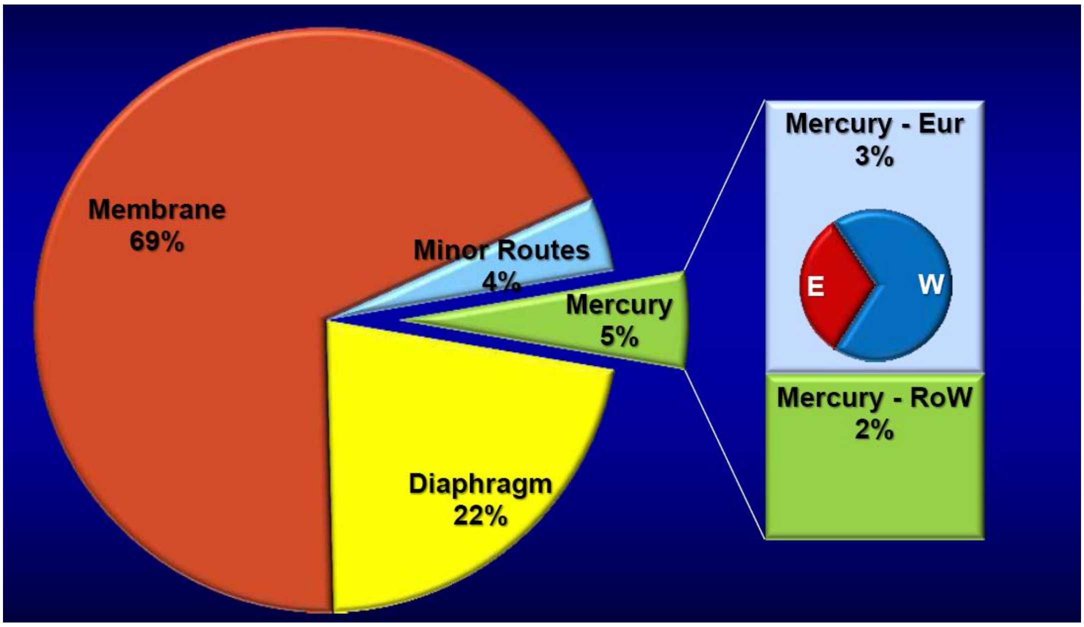
There are three major technologies for the industrial production of chlorine[7] :

- the mercury cell process: in this case, brine passes through a chamber which has a carbon electrode (the anode) suspended from the top. Mercury flows along the floor of this chamber and acts as the cathode. When an electric current is applied to the circuit, chloride ions in the electrolyte are oxidised to form chlorine gas.
- the diaphragm cell process: a porous diaphragm divides the electrolytic cell, which contains brine, into an anode compartment and a cathode compartment. The brine is introduced into the anode compartment and flows through the diaphragm into the cathode compartment. When an electric current passes through the brine, the salt's chlorine ions and sodium ions move to the electrodes and chlorine gas is produced at the anode.
- the membrane cell process: the membrane cell is very similar to the diaphragm cell, and the same reactions occur. The main difference with the previous process is that the two electrodes are separated by an ion-selective membrane, rather than by a diaphragm. Among the three available technologies, this is the most energy-efficient and the one with the lowest operating-costs.

[6] Caustic soda is an alkali which is widely-used in many industries, including the food industry, textile production, soap and other cleaning agents, water treatment and effluent control. Hydrogen is a combustible gas used in various processes including the production of hydrogen peroxide and ammonia as well as the removal of sulphur from petroleum derivatives. Depending on their sustainability programmes, more and more companies also use the excess hydrogen in fuel cells to generate electric power (Eurochlor, 2011).

[7] The source of the description of the three major technologies for chlorine production is the Everything Science website, available at: http://tinyurl.com/q9ntv86; accessed: 30 October 2013.

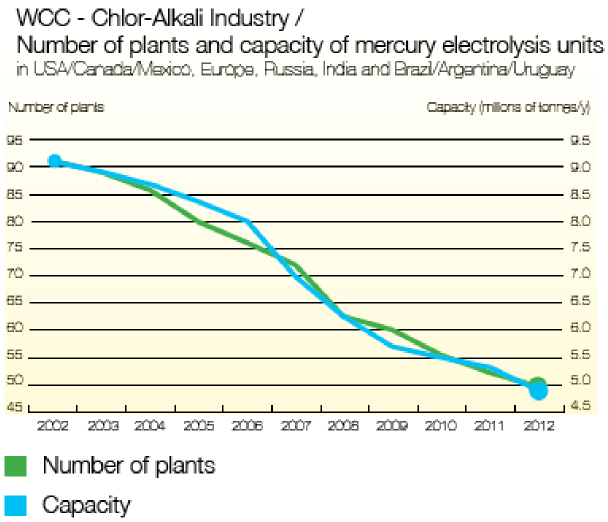
Figure 4. World chlorine capacity by production technology, 2012



Source: IHS (2013).

The mercury cell is the oldest technology and accounts for just about 5% of the world capacity (see Figure 4). Of the three processes, the mercury process uses the largest amount of electricity and is therefore the least-efficient available technology for chlorine production. The use of mercury technology also requires measures to prevent the harmful release of mercury into the environment. Chlorine producers are increasingly moving towards membrane technology (see Figure 5), which has much less impact on the environment and is the most cost-efficient in the long run (UNEP, 2012).

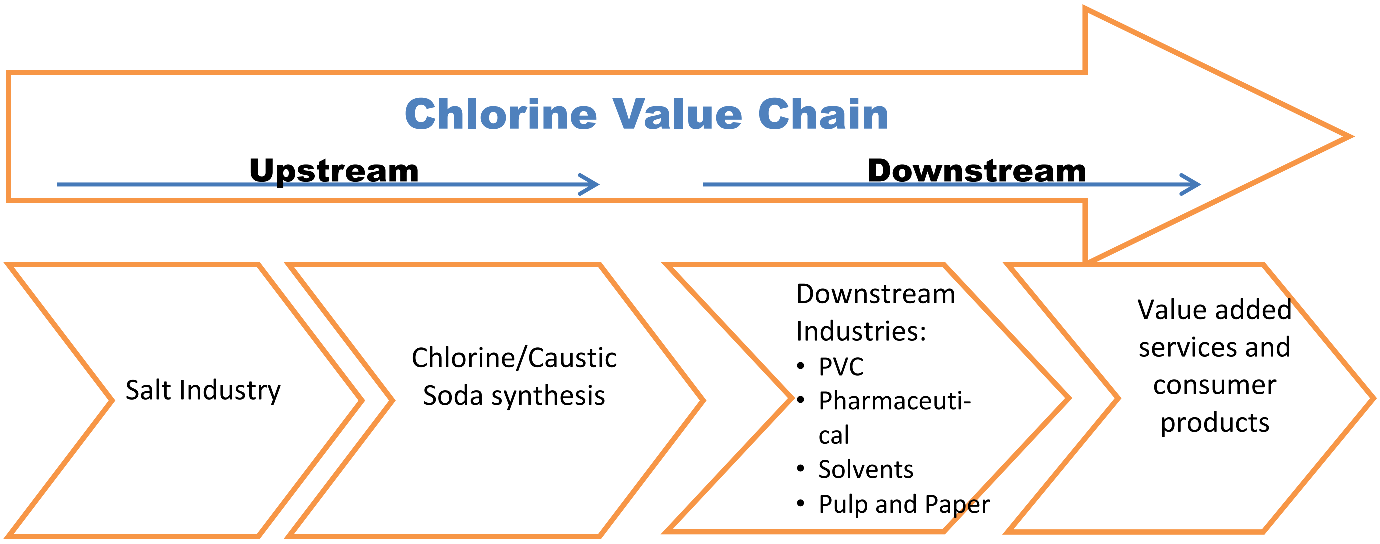
Figure 5. World number of plants and capacity using mercury cell technologies



Source: Eurochlor (2013).

1.4 The Chlorine value chain

Figure 6. Chlorine value chain



Source: Author.

The chlorine value chain presents a high degree of vertical integration among upstream and downstream players. The key factors determining the degree of vertical integration are the high transportation costs and the absence of a proper market for chlorine as such. Indeed, chlorine is used almost exclusively as an intermediate product since downstream industries in the value chain (e.g. PVC producers) produce themselves most of the chlorine required as an input in the production process. The value added across the value chain is therefore determined by the downstream industries, which process chlorine and use it as raw material for the production of different consumer products.

1.5 The EU chlorine market

The EU-27 has a total capacity for the industrial production of chlorine equal to around 12.2 million tonnes (see Table 2). The EU production is spread across 19 different member states and 72 production plants. The member state with the highest production capacity is by far Germany with a capacity of 5.2 million tonnes (19 plants, 42,5% of EU capacity), followed by France with a capacity of 1.4 million tonnes spread over 10 plants (11.6% of total EU capacity), Belgium (3 plants, 8.5% of EU capacity), the Netherlands (3 plants, 6.9% of EU capacity), Spain (9 plants, 6,1% of EU capacity) and the UK (2 plants, 6%). The remaining member states are responsible all together for about 18% of the total EU capacity.

Table 2. EU-27 capacity and number of plants per country, 2013[8]

Country	Capacity (k tonnes)	Plants	% EU capacity
GERMANY	5,187	19	42.49%
FRANCE	1,419	10	11.62%
BELGIUM	1,034	3	8.47%
THE NETHERLANDS	847	3	6.94%
SPAIN	744	9	6.09%
UK	729	2	5.97%
POLAND	339	3	2.78%
ITALY	426	6	3.49%
ROMANIA	384	2	3.15%
HUNGARY	291	1	2.38%
CZECH REPUBLIC	196	2	1.61%
PORTUGAL	142	2	1.16%
SWEDEN	120	1	0.98%
FINLAND	115	2	0.94%
SLOVAK REPUBLIC	76	1	0.62%
AUSTRIA	70	1	0.57%
GREECE	64	3	0.52%
SLOVENIA	16	1	0.13%
IRELAND	9	1	0.07%
TOTAL EU-27	**12,208**	**72**	100.00%

Source: Authors' elaboration on Eurochlor (2013).

Table 3 illustrates the share of the total European installed chlorine capacity between the three different chlorine production technologies. In particular, approximately 55% of the EU-27 capacity is based on the most efficient "membrane" technology, about 13% is based on the "diaphragm technology" and around 29% is still based on the "mercury technology".

Table 3. EU-27 capacity of chlorine per technology, 2013

Process	Capacity (k tonnes)	% EU total
Diaphragm "D"	1,635	13%
Mercury "Hg"	3,484	29%
Membrane "M"	6,788	55%
others	376	3%
Total[9]	12,283	100.00%

Source: Authors' elaboration on Eurochlor (2013).

---

[8] As of January 2013.

[9] There is a small divergence between the sum of the capacities of all technologies (12,283) and the total EU capacity figure reported in Table 2 (12,208) since, according to the information provided by Eurochlor (2013), the combined production capacity of one EU plant is smaller than the sum of the two technologies used (mercury and membrane) by this plant for chlorine production.

1.6 Sample selection

1.6.1 Sample selection criteria

To establish the sample for this study, the research team took as a starting point the complete list of chlorine plants published by Eurochlor[10] (2013)[11]. The criteria to establish the final sample of EU plants covered in the analysis are presented below. It should be noted that before selecting the sample, a number of European chlorine producers expressed their interest in participating in the study, in collaboration with Eurochlor. The research team duly took into account these expressions of interest when establishing the final sample, so as to enable both an authoritative analysis and limit the risk of receiving too few questionnaires.

Geographical coverage

The geographical criterion was chosen to ensure that different EU regions are represented in the analysis and to reflect the relative weight of the member states' chlorine capacity.

Capacity of plants

To reflect different capacities, the research team divided the total set of EU-27 plants into 3 sub-groups: those plants with a capacity higher than 300.000 tonnes per year have been identified as *large size*; those with a capacity higher than 100.000 t/y but lower than 300.000 t/y have been included in the *medium size* set; those with a capacity lower than 100.000 t/y have been included in the *small size* set. According to this classification, in the EU there are 10 large plants, 27 medium-size plants and 35 small plants.

Technology

The research team applied the technology criterion to reflect, to the extent possible, the shares of the three major production technologies (i.e. membrane technology, diaphragm technology and mercury technology) in the total EU installed chlorine capacity.

1.6.2 Sample statistics

The final sample consists of 9 plants[12], covering altogether around 12% of the total EU chlorine capacity. Concerning the size of the selected plants, 1 plant is defined in this study as large-size plant, 6 as are defined as medium and 2 as small (see Table 5). The membrane manufacturing technology represents 62% of the sample's total capacity, the mercury technology 32% and others 5%. The diaphragm technology is not represented in the sample (see Table 6).

---

[10] Eurochlor is the association of European chlorine producers.

[11] To double check the validity of this information, plants included in the final sample were asked to provide data on exact location, capacity and production. Production data were provided for the period between 2010 and 2012 (three years).

[12] Notably, the research team received questionnaires for 11 plants; however, as also described in the following section, two questionnaires were excluded from the final sample after a plausibility check.

Table 4. EU-27 chlorine plants statistics, 2013

	EU-27	%
Large	10	14%
Medium	27	37%
Small	35	49%
Highest (k tonnes)	1,585	
Lowest (k tonnes)	4	
Average Capacity (k tonnes)	170	
Median Capacity (k tonnes)	120	

Source: Authors' elaboration on Eurochlor (2013).

Table 5. Chlorine plants sample statistics

		% of sample
Total capacity (k tonnes, % EU-27)	1,500	12%
Average Capacity (k tonnes)	165	
Large	1	11%
Medium	6	67%
Small	2	22%

Source: Authors' elaboration.

Table 6. Chlorine plants sample statistics on production technologies

	% of sample
Diaphragm "D"	0%
Mercury "Hg"	32%
Membrane "M"	62%
Others	6%

Source: Authors' elaboration.

1.7 Methodology

1.7.1 Data collection

The analysis of the energy prices and costs for the chlorine sector was based on questionnaires sent to all plants included in the sample. The content of the questionnaire was discussed with chlorine industry experts to ensure that the technical specifications of the chlorine sector are properly reflected. In addition and with the help of the Chemical Industry Association (Cefic), the questionnaire was tested by one pilot plant. Strict confidentiality agreements were also signed with the companies participating in the study.

The research team received in total 11 questionnaires; however, two questionnaires were excluded from the final sample as provided data were not fully usable. All 9 participants provided detailed figures on the level and structure of energy prices as well as on energy consumption. Additionally, 5 out of the 9 sampled plants provided further data on production costs. Table 7 below provides an overview of the number of questionnaires received and used in the analysis of each section.

Table 7. Number of questionnaires received and used in each section

Total number received	11
Number included in the sample	9
Energy prices trends	9
Energy bill components	9
Energy intensity	9
Indirect ETS costs	9
Production costs	5

1.7.2 Data analysis and presentation

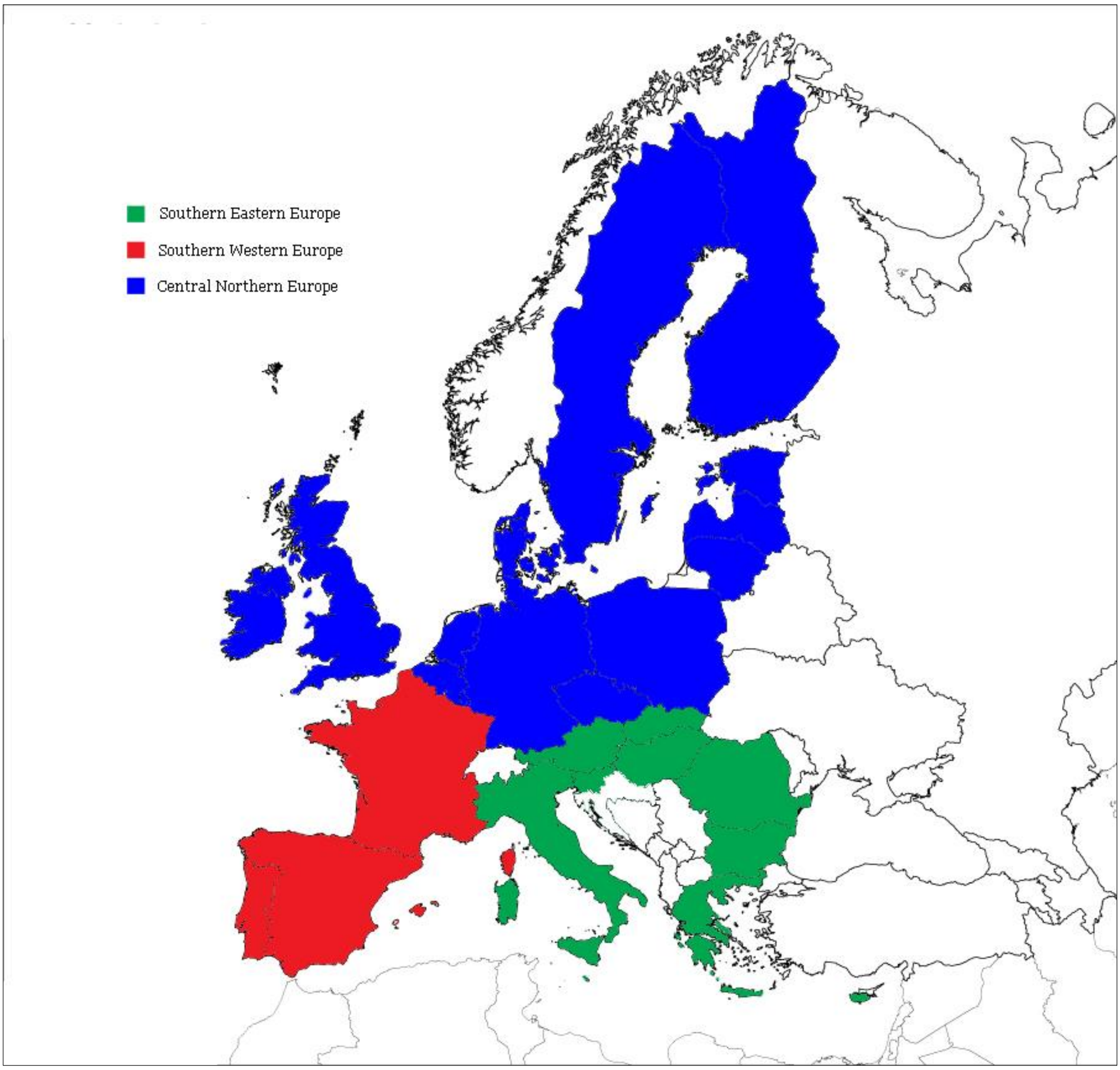
To ensure that no information can be attributed to any specific plant, the research team has applied the following geographical division for data aggregation. Notably, the research team did not receive any data from chlorine producers operating in the region defined below as Southern Eastern Europe:

a. **Southern Western Europe** (Spain, Portugal and France) is responsible for 19% of total EU chlorine production capacity and includes 3 of the sampled facilities.

b. **Central Northern Europe** (UK, Ireland, Belgium, the Netherlands, Luxembourg, Denmark, Germany, Poland, the Czech Republic, Latvia, Lithuania, Estonia, Sweden and Finland) is responsible for 70% of total EU chlorine production capacity and includes 6 of the sampled facilities.

c. **Southern Eastern Europe** (Italy, Slovenia, Austria, Hungary, Slovakia, Bulgaria, Romania, Greece, Malta and Cyprus) is responsible for 11% of total EU chlorine production capacity. The research team did not receive any questionnaires for facilities located in this region.

Figure 7. EU division in major geographical regions



Source: Own illustration.

Based on the geographical division explained above, section 1.8 presents the average energy prices paid by EU chlorine producers as well as the differences among the major EU regions. Importantly, prices represent average values of the price paid by each plant included in the sample within the region considered (Southern Western Europe, Central Northern Europe or EU-27). Each plant price has been weighted by a coefficient representing the specific year contribution of that plant to the total actual production of the region considered (Southern Western Europe, Central Northern Europe or EU-27). Section 1.9 focuses on the analysis of the energy bill components, while section 1.10 addresses the energy intensity of chlorine producers. The indirect ETS costs for chlorine producers are presented in section 1.11, while section 1.12 analyses the production costs for 5 sampled plants. Finally, section 1.13 reflects the general impressions of the participants on the current state of energy policy and markets.

1.7.3 Calculation of indirect ETS costs

The objective of the ETS cost calculations per sector in this study is to provide an estimation of the indirect ETS cost for the sub-sector between 2010 and 2012. The level of information is aggregated on a regional level, although the definition of those regions differs between cases studies.

The model for the indirect cost of EU ETS, per plant, is defined as:

Indirect costs

Indirect cost (€/Tonne of product) = Electricity intensity (kWh/Tonne of product)

** Carbon intensity of electricity (Tonne of CO_2/kWh)*

** CO_2 Price (€/Tonne of CO_2) * Pass-on rate*

Where:

- Electricity intensity of production: the amount of electricity used to produce one tonne of product. This amount is sector, plant and process specific;
- Carbon intensity of electricity generation indicates the amount of tonnes of CO2 emitted by utilities to generate one kWh;
- CO2 Price: is the average yearly market-price of CO2.
- Pass-on rate: the proportion of direct costs faced by utilities (disregarding any mitigating effects from free allocation) that they pass on to electricity consumers.

Sources:

- Electricity intensity of production; this was acquired from interviews with and questionnaires answered by industry members.
- Carbon intensity of electricity generation: the maximum regional carbon intensity of electricity is utilised, provided by the Commission's Guidelines on State aid measures[13]. Note that these figures are not national. Member States who are highly interconnected or have electricity prices with very low divergences are regarded as being part of a wider electricity market and are deemed to have the same maximum intensity of generation (for example, Spain and Portugal).
- CO2 Price: Yearly averages of the daily settlement prices for Dec Future contracts for delivery in that year. The daily settlement prices were reported by the European Energy Exchange.

[13] Communication from the Commission: Guidelines on certain State aid measures in the context of the greenhouse gas emission allowance trading scheme post-2012 (2012/C 158/04).

Table 8. Average yearly prices per tonne of CO2 (€)

Year	2010	2011	2012
CO_2 Price	14.48	13.77	7.56

1.7.4 Validation of information

The research team has used a combination of an internal cross-sectoral comparison of energy prices reported by all participant sectors and sub-sectors[14] and a validation through EU energy statistics publications[15]. To test consistency, the research team conducted targeted interviews with chlorine producers included in the sample. No secondary sources could be retrieved on plant-specific energy costs of chlorine producers.

The validation of the production costs for the EU chlorine industry is a complex task. Chlorine is an intermediate product which companies usually use as an input for their downstream activities. As a result, it is not possible to retrieve meaningful information from companies' balance sheet data as regards this specific product line. Nonetheless, data consistency for production costs was ensured by comparing data submitted by different producers and data submitted by the same producer for different years and asking for clarification and integrations whenever inconsistency was detected.

1.8 Energy prices trends

1.8.1 Introduction

This section will present the energy prices for the chlorine industry. All sampled chlorine producers use electricity as a primary source of energy, while a number of them[16] also use steam as a secondary energy carrier; however the number of data points is too low to allow for an analysis of steam as a secondary energy carrier. At the same time, natural gas is used by only one plant in the sample. For these reasons, the analysis is limited to electricity costs. As shown in Table 9 below, electricity is responsible for the lion's share of total energy costs and also accounts for 43-45% of total production costs. Note that the energy prices presented in this section are delivered at plant excluding VAT; hence include possible exemptions[17] from taxes, levies or transmission costs but exclude any interruptibility discounts[18].

---

[14] This refers to all 5 sub-sectors included in the study i.e. the float glass sector, the wall and floor tiles/bricks and roof tiles (ceramics sector) and the two chemicals sub-sectors (ammonia and chlorine).

[15] Validation was conducted through Eurostat statistics, available at: http://tinyurl.com/mt2p27d; accessed: 28 October 2013.

[16] See section 1.10.

[17] Notably, the majority of producers mentioned that they are entitled to reductions/exemptions from network tariffs, taxes or levies.

[18] This refers to various forms of remuneration provided to companies which accept cuts in their electricity supply at the request of the transmission system operator. Two participants in the study reported that they provide interruptibility services and thus in practice they face lower energy costs than the ones reported in this section.

Table 9. Share of electricity in total energy costs and total production costs[19]

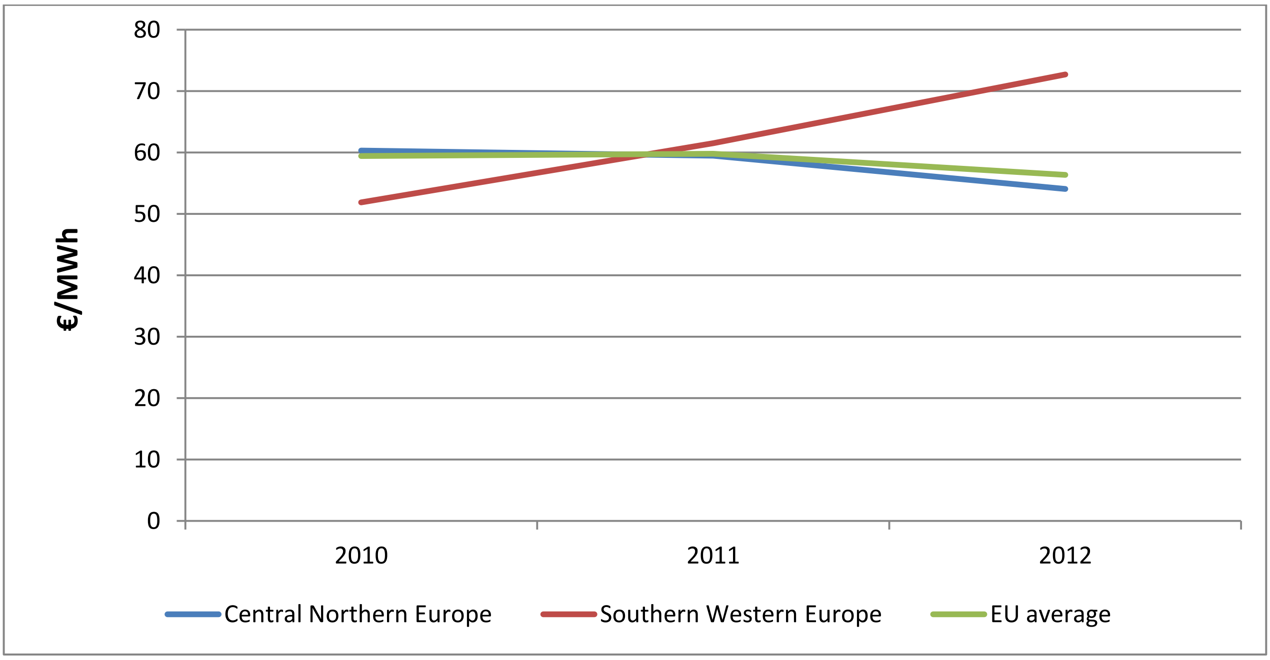
	Share in total energy costs, %	Share in total production costs, %
Electricity	91%[20]	43-45%

Source: Author's elaboration based on data from questionnaires.

1.8.2 General trends

Between 2010 and 2011 average electricity prices increased marginally from 59.4 €/MWh to 59.8 €/MWh, or +0.7% (Table 10). This trend reversed from 2011 to 2012 as electricity prices decreased from by 5.7% i.e. from 59.8 €/MWh to 56.4 €/MWh. This means that for the whole period – 2010 to 2012 – electricity prices paid by sampled EU chlorine producers decreased by around 5%, i.e. from 59.4 €/MWh to 56.4 €/MWh. It should be noted that the trends in the EU average are largely driven by the trends in the prices in Central Northern Europe, as this region's weight in the sample is higher than that of Southern Western Europe, thus affecting considerably the weighted average[21]. Section 1.8.3 below focuses in greater detail on the decrease in electricity prices in Central Northern Europe.

Figure 8. Electricity prices paid by EU chlorine producers, (€/MWh)



Source: Author's elaboration based on data from questionnaires.

[19] The figure on the share of electricity costs in total energy costs is an average for the full sample (nine plants) and the three-year period studied. The figures on the share of electricity costs in total production costs are averages for the five plants (see section 1.12 for more details) that provided data on production costs and thus have a lower representativeness.

[20] Ranging from 91.84% in 2010 to 91.18% in 2012.

[21] All presented figures are weighted averages that have been calculated on the basis of the actual annual production of the sampled plants. See also section 1.7.2.

Table 10. Descriptive statistics for electricity prices paid by sampled EU chlorine producers (€/MWh)

	2010	2011	2012
EU (average)	59.4	59.8	56.4
Southern Western Europe (average)	51.9	61.5	72.7
Central Northern Europe (average)	60.3	59.5	54.1

Source: Author's calculation based on data from questionnaires.

Figure 9. Electricity prices paid by EU chlorine producers (box plots), (€/MWh) [Confidential]

1.8.3 Regional differences

Central Northern Europe

For the period covered by the study – 2010 to 2012 – the average price decreased by 10.3% (from 60.3 to 54.1 €/MWh) with a decrease of about 1.3% from 2010 to 2011 and 9% during the following year. As explained in section 1.8.2, the downward trend in the EU average electricity price between 2011 and 2012 was driven by the decrease in the prices paid in Central Northern Europe. Figure 12 illustrates that in this region the share of the energy component in the total energy bill is very high and also increased from 84% in 2010 to 89% in 2012. This should be considered in conjunction with the fact that the majority of respondents from this region reported that they buy electricity either on spot basis or on the basis of spot and future prices. Thus, an explanation that could be given for the decrease of electricity prices is that producers in this region benefited from decreasing wholesale market prices, also due to the increasing share of renewables.

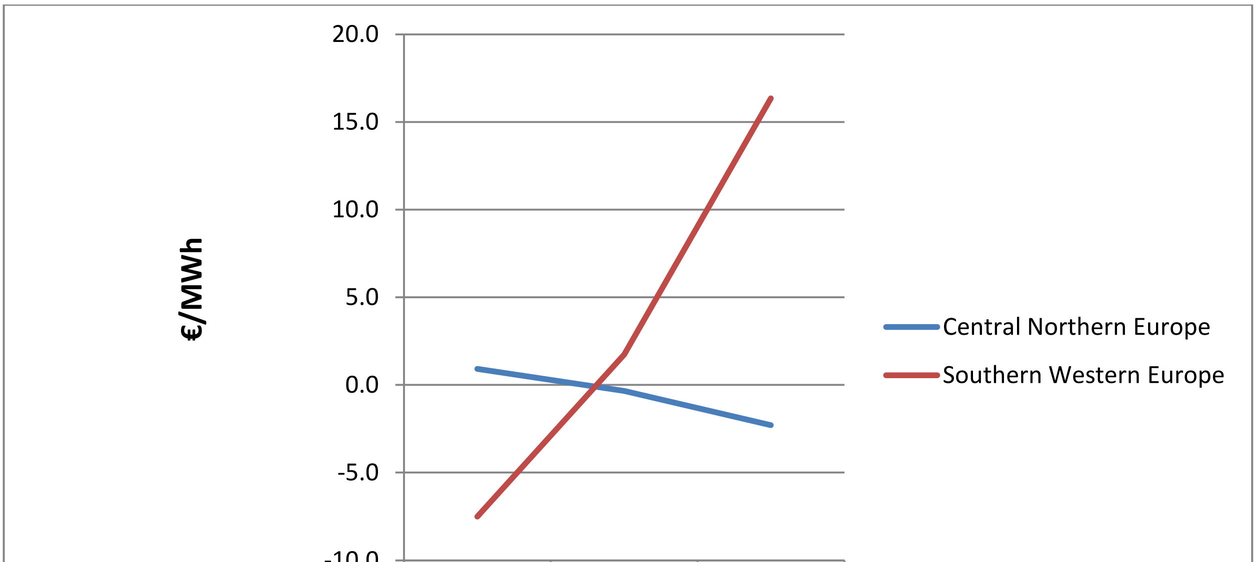
Southern Western Europe

There is a steep upward trend in the electricity prices paid by chlorine producers in Southern Western Europe. In particular, between 2010 and 2012 electricity prices rose sharply by some 40% from 51.9 €/MWh to 72.7 €/MWh. From 2010 to 2011 they increased by about 18.5% and from 2011 to 2012 by 18.2%. As a result, chlorine producers in this region faced higher electricity prices compared to producers in Central Northern Europe, except for the year 2010, when the average electricity price was lower in this region (51.9 versus 60.3 €/MWh).

Regional gaps

Figure 10 below provides a graphical presentation of the divergent trends and the gap between the EU average price and the two regional average prices. In 2010, producers in Southern Western Europe were paying on average 7.5 €/MWh less than the EU average. In just two years however, this trend reversed, as in 2012 producers were paying 16.3 €/MWh more. On the contrary, while in 2010 the average electricity price in Central Northern Europe was 0.9 €/MWh higher than the EU average, in 2012 this value reached minus 2.3 €/MWh.

Figure 10. Regional gaps of electricity price with EU average, (€/MWh)



	2010	2011	2012
Central Northern Europe	0.9	-0.3	-2.3
Southern Western Europe	-7.5	1.7	16.3

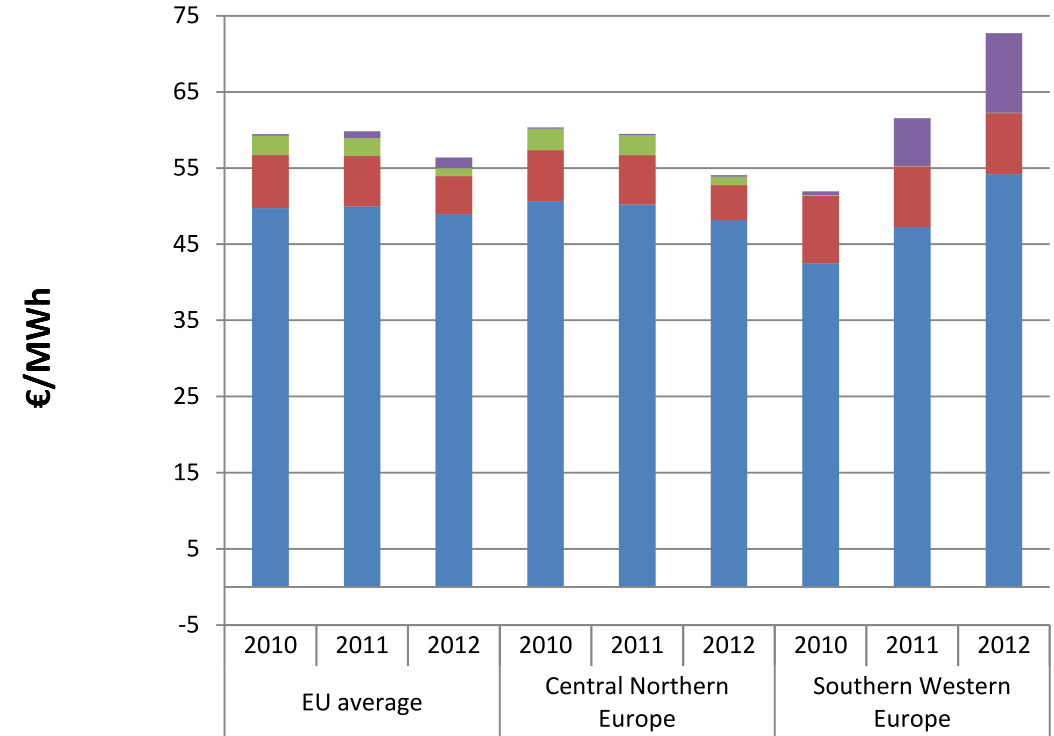
Source: Author's elaboration based on data from questionnaires.

1.9 Analysis of energy bills components

1.9.1 General trends

This section illustrates the various components of the electricity bill: i) energy component, ii) grid fees, iii) RES levy and iv) other non-recoverable taxes. As shown in Figure 11, the energy component accounts for the lion's share of the electricity price, while its contribution to the total electricity bill increased from 83.7% in 2010 to 86.8% in 2012. However, in absolute terms the energy component decreased somewhat from 49.76 €/MWh in 2010 to 48.94 €/MWh in 2012 (-1.6%).

Figure 11. Components of the electricity bill paid by EU chlorine producers (€/MWh)

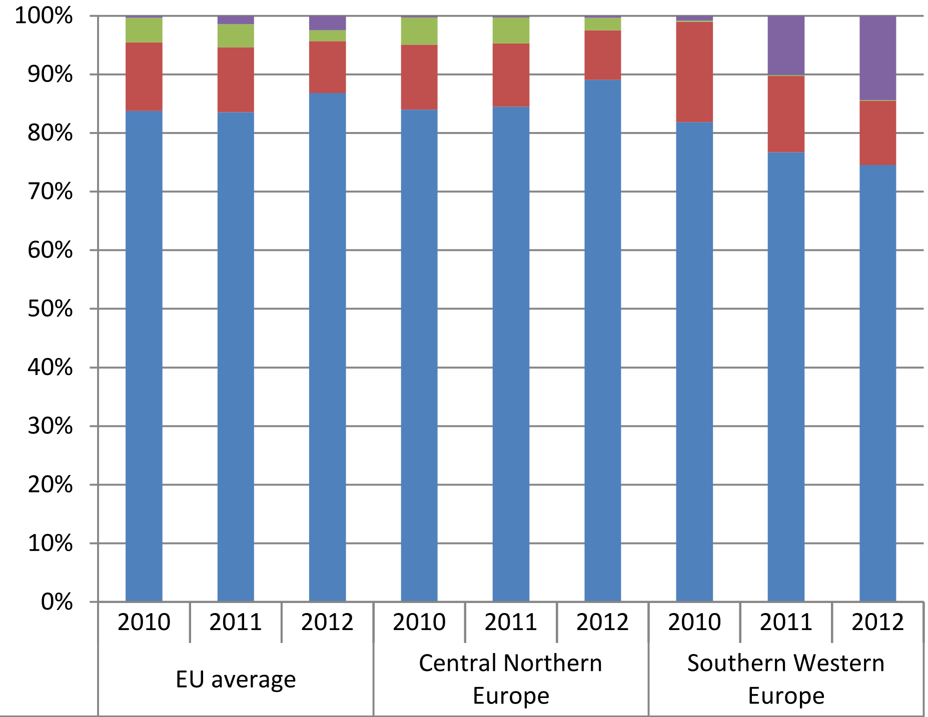


	EU average 2010	EU average 2011	EU average 2012	Central Northern Europe 2010	Central Northern Europe 2011	Central Northern Europe 2012	Southern Western Europe 2010	Southern Western Europe 2011	Southern Western Europe 2012
Other non-recoverable taxes	0.20	0.87	1.41	0.17	0.17	0.20	0.44	6.24	10.47
RES levy	2.49	2.34	1.02	2.81	2.63	1.15	0.12	0.10	0.07
Grid fees	6.97	6.63	4.98	6.69	6.45	4.58	8.86	7.98	7.97
Energy component	49.76	49.96	48.94	50.66	50.22	48.14	42.49	47.22	54.20

Source: Own calculation based on questionnaires.

Concerning the other price components, the share of grid fees in the total electricity bill decreased from 11.7% in 2010 to 8.8% in 2012; this represents a decrease in absolute values from 6.97 €/MWh in 2010 to 4.98 €/MWh in 2012 (-28.6%). The contribution of RES levies in the total bill decreased substantially from 4.2% in 2010 to 1.8% in 2012. In absolute terms, RES levies decreased from 2.49 €/MWh in 2010 to 1.02 €/MWh in 2012 (-59%). On the contrary, the impact of other non-recoverable fees in the total bill increased from 0.3% in 2010 to 2.5% 2010. This represents an increase in absolute values between 2010 and 2012 from 0.2 to 1.41 €/MWh.

Figure 12. Components of the electricity bill paid by EU chlorine producers (in %)



	EU average 2010	EU average 2011	EU average 2012	Central Northern Europe 2010	Central Northern Europe 2011	Central Northern Europe 2012	Southern Western Europe 2010	Southern Western Europe 2011	Southern Western Europe 2012
Other non-recoverable taxes	0.3%	1.4%	2.5%	0.3%	0.3%	0.4%	0.9%	10.1%	14.4%
RES levy	4.2%	3.9%	1.8%	4.7%	4.4%	2.1%	0.2%	0.2%	0.1%
Grid fees	11.7%	11.1%	8.8%	11.1%	10.8%	8.5%	17.1%	13.0%	11.0%
Energy component	83.7%	83.5%	86.8%	84.0%	84.4%	89.0%	81.9%	76.7%	74.5%

Source: Own calculation based on questionnaires.

1.9.2 Regional differences

Southern Western Europe

Although in absolute terms the energy component increased significantly[22] between 2010 and 2012, its contribution to the total electricity bill decreased from 81.9% to 74.5%. The contribution of grid fees also decreased[23] from 17.1% in 2010 to 11% in 2012. At the same time, the impact of non-recoverable taxes on the bill rose from 0.9% in 2010 to 14.4% in 2012; this represents an increase in absolute values from 0.44 €/MWh in 2010 to 10.47 €/MWh in 2012 (+2279%). RES levies in this region have a very small share in the total energy bill, which decreased from 0.2% in 2010 to 0.1% in 2012.

Central Northern Europe

In Central Northern Europe, the energy component has an even higher impact on the total electricity prices than in Southern Western Europe. In 2010, its share in the total bill accounted for 84%, while in 2012 it increased to 89%. However, the absolute value of the

[22] Specifically, its absolute value increased from 42.49 €/MWh in 2010 to 54.2 €/MWh in 2012.
[23] In absolute terms, grid fees deceased from 8.86 €/MWh in 2010 to 7.97 €/MWh in 2012.

energy component decreased from 50.66 €/MWh to 48.14 €/MWh (-5%). In 2010, the contribution of RES levies to the total electricity bill was 4.7%; however, in 2012 this figure decreased to 2.1%. Compared to Southern Western Europe, the impact of other non-recoverable taxes in this region is almost marginal, and increased from 0.3% in 2010 to 0.4% in 2012.

1.10 Energy intensity

This section assesses the energy intensity of sampled chlorine plants in terms of physical output (unit: MWh/tonne). It focuses on electricity, which dominates the energy consumption of the sampled producers. Specifically, the average share of electricity consumption in total energy consumption was about 87%[24] during all three years considered in the study. The figures presented below are based on the electricity consumption data and chlorine production levels provided by all 9 sampled chlorine producers.

1.10.1 General trends

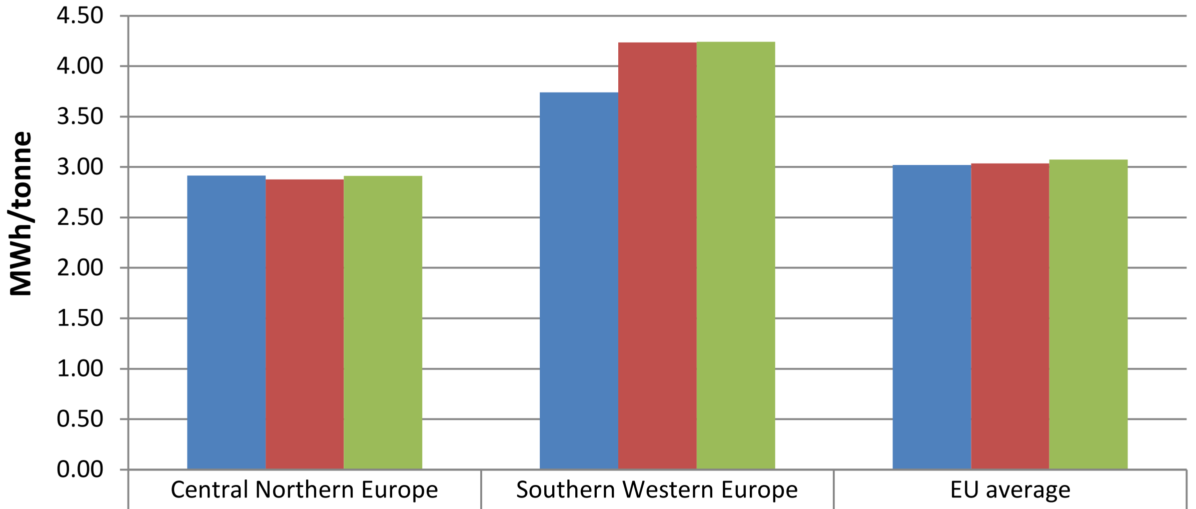
Figure 13 below presents the energy intensity per tonne of chlorine product of the sampled EU chlorine plants. Augmenting from 3.02 MWh/tonne in 2010 to 3.07 MWh/tonne in 2012, the average intensity of EU electricity consumption has increased by 1.7%. This increase has been mainly driven by the increase in Southern Western Europe, as in Central Northern Europe the electricity intensity has remained rather stable (see next section 1.10.2). It should be noted that 4 out of 9 interviewees reported that they have made energy efficiency investments in recent years[25], primarily triggered by energy cost savings considerations but also by public policy[26].

[24] This figure represents an average for 8 out of 9 plants, as one participant could not provide full energy consumption data for other energy sources apart from electricity. Notably, 5 out of 9 producers also used steam/hot water and one natural gas.

[25] This refers to the three-year period addressed by the study or earlier.

[26] It is noteworthy that another participant reported that large-scale energy efficiency investments are not made on a very regular basis and are mainly driven by public policy, while a further one mentioned that energy efficiency investments are generally triggered by both cost savings and public policy.

Figure 13. Electricity intensity of EU chlorine producers (MWh/tonne)



	Central Northern Europe	Southern Western Europe	EU average
2010	2.92	3.74	3.02
2011	2.88	4.24	3.04
2012	2.91	4.24	3.07

Source: Author's elaboration based on data from questionnaire.

1.10.2 Regional differences

Southern Western Europe

Southern Western Europe exhibits a higher average electricity intensity (or lower energy efficiency) compared to Central Northern Europe during the three-year period covered by this study. The average electricity intensity increased from 3.74 MWh/tonne in 2010 to 4.24 MWh/tonne (+13.4%) in 2011 and remained stable between 2011 and 2012.

Central Northern Europe

In contrast, in Central Northern Europe the average electricity intensity remained rather stable during the analysed period; it decreased by approximately 1.4% between 2010 and 2011 and then increased by around 1% between 2011 and 2012. In 2010 it was 2.92 MWh/tonne and in 2012 2.91 MWh/tonne.

1.11 Indirect ETS costs

1.11.1 Results

The calculation of indirect ETS costs for the chlorine industry was based on the electricity consumption and total production figures provided by the sampled EU chlorine producers as well as on the maximum regional CO_2 emission factors of electricity generation and price of emission allowances (see also 1.7.3). Tables 11, 12 and 13 summarise the indirect costs borne by EU chlorine producers, using different pass-on rates.

Table 11. Chlorine indirect costs, averages per region (Euro/tonne of chlorine)

	Central Northern Europe	Southern Western Europe	EU average
2010	19.27	24.71	21.08
2011	18.02	26.18	20.74
2012	10.07	15.98	12.04

Pass-on rate: 0.6

Table 12. Chlorine indirect costs, averages per region (Euro/tonne of chlorine)

	Central Northern Europe	Southern Western Europe	EU average
2010	25.69	32.95	28.11
2011	24.02	34.91	27.65
2012	13.42	21.30	16.05

Pass-on rate: 0.8

Table 13. Chlorine indirect costs, averages per region (Euro/tonne of chlorine)

	Central Northern Europe	Southern Western Europe	EU average
2010	32.11	41.19	35.14
2011	30.03	43.64	34.56
2012	16.78	26.63	20.06

Pass-on rate: 1

None of the plants included in the sample rely on long-term contracts or self-generation to cover their electricity consumption. They all acquired electricity through wholesale markets or short-term contracts with one supplier.

The drop in indirect-ETS costs across all regions between 2011 and 2012 can be largely attributed to a sharp decrease in EUA prices (from a yearly average of 13.77 Euros per EUA in 2011 to a yearly average of 7.56 Euros per EUA in 2012).

There are large inter-regional differences in indirect costs. Indirect costs are significantly higher in the Southern Western European region when compared with the Central Northern European region. There are two specific differences between these two regions that influence the inter-regional differences:

- the maximum regional CO_2 emissions factor[27], which is lowest in Southern Western Europe (around 0.60 tonnes of CO2 per MWh) and highest in Central Northern Europe (around 0.75 tonnes of CO2 per MWh) and

- differences in electricity intensities between plants. Chlorine plants in Southern Western Europe consume on average circa 4.7 MWh/tonne of chlorine, compared with circa 3 in Central Northern Europe.

1.11.2 Key findings

1) The inter-regional differences are relatively large.
2) Indirect ETS costs in Southern Western Europe are far higher than in the Central Northern European region, caused largely by the significantly higher electricity intensity of production in Southern Western Europe.
3) Although the average CO2 intensity of electricity generation is higher in Central Northern Europe, a lower average of electricity intensity of production results in lower indirect costs compared to Southern Western Europe.
4) Electricity intensity of production differs significantly between plants within the same region.
5) The ETS indirect cost was significantly lower in 2012 compared to the previous years, mainly because the price of EUAs was significantly lower in 2012.

1.12 Production costs

This section presents an analysis of the production costs for EU producers of chlorine. Due to the intermediate nature of the good, it is not possible to retrieve meaningful data from publicly available sources – including companies' balance sheets. Therefore, to estimate production costs of chlorine it is necessary to rely on information provided directly by companies that can extract relevant data from their analytical accounting. The research team ensured the consistency of those cost figures by comparing data submitted by

[27] As defined and listed in Annex IV of the 'Guidelines on certain State aid measures in the context of the greenhouse gas emission allowance trading scheme post-2012' (2012/C 158/04).

different producers and data submitted by the same producer for different years and asking for clarification and integrations whenever inconsistency was detected.

As explained in section 1.7.1, a questionnaire to collect data on production costs was sent to all the companies included in the sample. Data over the period 2010-2012 were provided by only five out of nine plants. Thus, due to the lower response rate, the representativeness of the following figures is lower than of the figures presented in the other sections of this report. Furthermore, one of these plants did not provide figures for 2010.

All figures are expressed in Euro per tonne of product at current prices. For the responding plants, the following elements are estimated for the years 2010, 2011, and 2012:

- Total production costs, whose estimate has been provided by companies and includes all production costs, *i.e.* cost of finished chlorine, other operating expenses, depreciation, amortization, and financial expenses referred to the product line;
- Electricity costs, provided by companies in terms of €/MWh and converted into €/tonne using the corresponding energy intensities of the production process.

The figures reported in Table 14 are weighted averages for the respondent plants, based on individual plant production for each year.

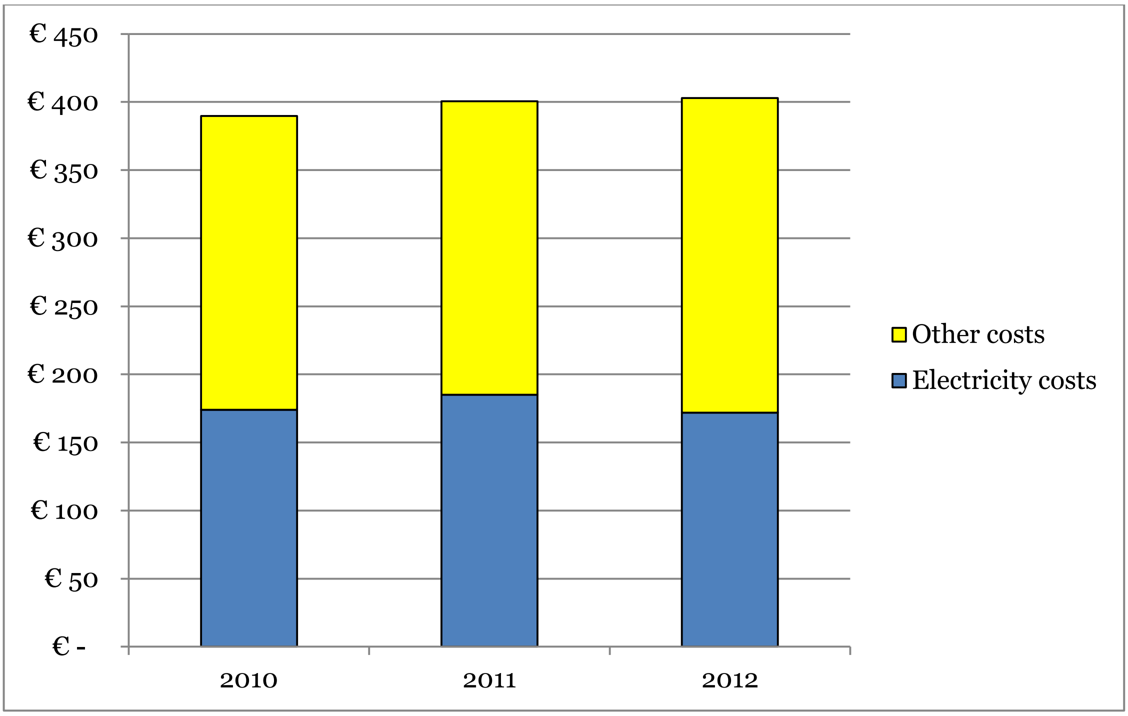
Table 14. Production costs of EU chlorine producers

	2010	2011	2012
Number of plants	4	5	5
Total production costs (€/tonne)	€ 389.70	€ 400.51	€ 402.92
Electricity costs (€/tonne)	€ 173.96	€ 185.17	€ 171.94

Source: Authors' elaboration on companies' data.

Total production costs experienced a slight and constant increase over the period 2010-2012 (+3%; +13 €/tonne). As for electricity costs, the growth registered between 2010 and 2011 (+6%) was followed by a comparable decrease between 2011 and 2012 (-7%), thus leading to an overall cost reduction over the observation period (-1%). All in all, electricity costs represent a significant share of total production costs, going from about 45% in 2010 to some 43% in 2012 (see Figure 14).

Figure 14. Total production costs of EU chlorine producers (€/tonne)



Source: Authors' elaboration on companies' data.

1.13 General impressions

The research team used the questionnaires to (*inter alia*) ask EU chlorine producers about their impressions of the effects of liberalisation. The respondents had divergent views on the impact of liberalisation on the energy markets. Some argued that liberalised markets have contributed to lower energy prices, while others claimed that liberalisation has resulted in higher prices. Two participants also mentioned that an integrated EU market would have a positive impact on energy prices.

References

Centre for Science and Environment, (n.d.), *Ecological and economic profile of the caustic-chlorine industry,* available at: http://www.cseindia.org/node/283; accessed: 30 October 2013.

Eurochlor, (2013), *Chlorine Industry 2012-2013. Towards a new European Industrial Policy for more Competitiveness*, available at: http://tinyurl.com/lbu8e2e**;** accessed: 30 October 2013.

Eurochlor, (2010), *The European Chlor-Alaki industry: an electricity intensive sector exposed to carbon leakage*, available at: http://tinyurl.com/p63fvnt; accessed: 30 October 2013.

Eurochlor, (2011), *The Euro Chlor Sustainability Programme. Results of the 2000-2011 Programme. The 2011-2021 Programme*, available at: http://tinyurl.com/km3neq8; accessed: 31 October 2013.

Everything Science, (n.d.), *The chloralkali industry*, available at: http://tinyurl.com/q9ntv86; accessed: 30 October 2013.

Greener-industry, (2012), *Chlorine Facts and Figures*, available at: http://www.greener-industry.org.uk; accessed: 27 August 2013.

HIS, (2013), *Chlorine State of the Industry: Global Renaissance - Challenges and Opportunities*, presentation by Steven Brien.

UNEP, (2012), *Conversion from Mercury to Alternative Technology in the Chlor-Alkali Industry*, UNEP Global Mercury Partnership Chlor-Alkali Area, available at: http://tinyurl.com/k6r9kd5; accessed: 29 October 2013.

World Chlorine Council, (2012), *Sustainable Report,* available at: http://tinyurl.com/q4zzjfx; accessed: 27 August 2013.