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Production costs from energy-intensive industries in the EU and third countries

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Abstract:
Production costs of energy-intensive industries in the EU and third countries.

This report compares estimated production costs from four energy-intensive industries (steel, cement, chemical and non-ferrous metals) in the European Union and some third countries. Production costs have been estimated following a bottom-up approach, i.e. using information at facility level from a representative number of facilities. Costs are broken down to key factors, such as material, labour and energy costs and exclude capital costs (depreciation and interest). Moreover, the energy costs are estimated considering the effect of the state of technologies and the fuel mix in each country.

For the iron and steel industry the production costs of hot-rolled coil and wire rod are analysed as representative flat and long products, respectively. The production costs of these products have been estimated for both the integrated route (blast furnace-basic oxygen furnace) and the recycling route (electrical arc furnace). For the chemical industry, the products analysed are ammonia, methanol, ethylene and propylene; whereas for the non-ferrous metals the analysis is focused on primary aluminium production, copper cathodes and slabs of zinc.

Most of the EU28 production costs are ranked (when compared with certain competitor countries) between the 75th percentile and the maximum production cost. These costs are highest in the EU relative to other countries or regions in the case of flat products from the recycling route, ammonia and methanol. For long products -from the recycling route-, flat products -from the integrated route-, ethylene, propylene -refinery grade- and copper anode the EU28 production costs are between the median (the median separates the higher half of the costs from the lower half) and the 75th percentile of all production costs estimated. In the case of cement, the EU28 production cost is quite similar to the value of the median cost. There are also cases in which the EU28 production costs were among the lowest costs, namely for copper cathode and zinc slabs. It is worth noting that the contribution of energy costs to production costs is the highest in the EU only for methanol and ammonia. For all other products and industries analysed (including methanol and ammonia), other components of the cost (raw materials, labour and others or feedstock) contribute more to final costs than energy (natural gas is considered as a feedstock for methanol and ammonia). It is also noteworthy that, in most industries and products, the behaviour of credits (by-products, home scrap, electricity production from waste gases or from combined heat and power) contributes to reduce production costs more in the EU than it does in other countries or regions.

Contents

Executive summary

Issues of competitiveness in European energy-intensive industries are at a high level of importance. As a response to claims from representatives of energy-intensive industry that costs related to regulation are responsible for considerable troubles, and in order to get a better understanding of the dimension of regulatory costs, different services of the European Commission are undertaking studies related to energy prices, regulatory costs, competitiveness, industrial policy orientations and technological limits. The communication *For a European Industrial Renaissance* [EC, 2014] noted that operational costs might be higher than those of competitors, especially energy costs.

It should also be emphasised that this study looks only at production costs which can be estimated quantitatively, and does not look at wider issues such as governance, regulatory predictability, political stability, the availability of qualified workforces and proximity to markets for products and further processing and manufacture.

This document shows the results of the research and data collection exercise carried out by the Joint Research Centre (JRC) using public and (where possible) commercial and industry data, aiming to establish different parameters that affect the cost and production process of certain energy-intensive industries (cement, iron and steel, chemicals and non-ferrous metals). For the chemical industry, the analysis is limited to ammonia, methanol, ethylene and propylene and for the non-ferrous metals, it is limited to aluminium, copper and zinc. Besides the EU as a whole, the countries whose production costs are quantified vary per industry; however, for all industries and countries, production costs are estimated by using a sample of facilities that is considered to be representative.

The specific cost of thermal energy consumed by the EU **cement industry** is quite similar to that of the country with the lowest cost of thermal energy of those studied (China). When including estimated electricity costs, the EU energy costs per tonne of cement are well below those in Ukraine and Egypt and in the middle of the five countries studied. The difference between average production costs in China and Algeria (36 EUR/t) and the EU average costs (48 EUR/t) is lower than the transportation cost of crossing the Mediterranean Sea (15 EUR/t).

Concerning the **iron and steel industry**, in almost all cases analysed, the country with the highest costs, Japan, is not far higher than the position of the EU, while Russia is one of the countries with the lowest costs. The variability in energy costs observed does not affect the production costs as much as the variability in other components of the costs. For the products, both flat and long, and almost for all countries studied, the total cost in 2013 for the electrical arc furnace (EAF) route (recycling route) was higher than for the blast furnace-basic oxygen furnace (BF-BOF) route (integrated route). This is mainly due to the raw materials costs (scrap) rather than the energy costs.

The decisive factor in **ammonia and methanol** production costs is feedstock availability. In the Middle East and in Russia where feedstock (mainly natural gas) is produced locally, production costs are much lower. The EU has higher costs for both products. Estimated average production costs for the EU ammonia industry in 2013 are about 14 % lower than the ammonia price in the western European market. Methanol production in the EU seems to have been facing strong competition.

In **ethylene and propylene** production, feedstock is an important component of the costs, but as steam cracking is a multi-product process, the credits obtained thanks to co-products produced compensate for part of the costs. The higher the price of fuels in a country, the higher the feedstock costs and the credits obtained.

A major feature of steam cracking is the variety of feedstocks that can be used. Different parts of the world have adopted the feedstock most easily available. North America and Saudi Arabian production is based on domestic natural gas liquids, primarily ethane and propane, while ethylene producers in Europe and Russia favour petroleum liquid feeds. Ethane-based industries in general have lower production costs than naphtha-based industries, but the total costs are comparable in all the countries analysed. The price of ethylene in 2013 in the EU was about 1 125 EUR/t, and the average total costs amounted to 748.4 EUR/t when considering ethylene as the main product or to 816.2 EUR/t when both olefins are considered as a product. In the case of propylene, almost all countries have comparable production costs, except Ukraine where propylene is produced only by steam cracking. Production costs are higher in Ukraine as steam cracking is not a process producing mainly propylene.

Estimated average production costs for the EU **aluminium industry** in 2012 and 2013 are (10 % and 7 %) lower than the aluminium prices those years. However, it should be noted that capital costs are excluded from the analysis. In the EU, the presence of some bilateral contracts makes that some producers have similar production costs to Norwegian, Icelandic and some Russian competitors. Low electricity prices in Iceland, Norway and Russia, due to hydroelectric power, explain much of their cost advantage compared to the production costs in the EU, where energy costs account for around 40 % of total production costs. These low power prices also reduce the estimated average production costs.

The productivity of the EU **copper industry** is one of the highest in the world. In the case of copper smelters, the EU has similar production costs to South American countries which are the leaders in producing copper, because of their proximity to raw materials. China has low labour costs which reduces overall costs. In the case of copper refineries, the EU has among the lowest production costs. The higher recycling rate is an advantage for the EU as copper anodes can be produced by either the primary or the secondary route and be processed in the same copper refineries. The EU copper industry has the lowest treatment and refining charges compared to the rest of the countries studied. Based on a rough estimation of the copper concentrates price, the sum of EU copper concentrates costs and treatment and refining charges was about 10 % lower than the average copper price in the London Exchange Market in 2013.

EU **zinc** smelters have some of the lowest total average production costs among the countries studied. EU **zinc** smelters also have one of the highest productivities. European (EU and Norway) treatment charges are the second lowest of the analysed countries. The sum of zinc concentrates (roughly estimated) and treatment costs in the EU was about 16 % lower than the average zinc price in the London Exchange Market in 2013.

1. Introduction

Issues of competitiveness in European energy-intensive industries are at a high level of importance. As a response to claims from representatives of energy-intensive industry that costs related to regulation are responsible for considerable troubles, and in order to get a better understanding of the dimension of regulatory costs, different services of the European Commission are undertaking studies related to energy prices, regulatory costs, competitiveness, industrial policy orientations and technological limits. The communication *For a European Industrial Renaissance* [EC, 2014] noted that operational costs might be higher than those of competitors, especially energy costs. It should also be emphasised that this study looks only at production costs which can be estimated quantitatively, and does not look at wider issues such as governance, regulatory predictability, political stability, the availability of qualified workforces and proximity to markets for products and further processing and manufacture.

This document summarises the methodology and findings of the analysis carried out in the four annexes corresponding to the studies for the iron and steel, cement, chemical and non-ferrous metals industries. The four annexes show the results of the research and data collection exercise carried out by the JRC, using public, and (where possible) commercial and industry data, aiming to establish different parameters that affect the cost and production processes of energy-intensive industries.

Besides the EU as a whole, the countries whose production costs are quantified are:

- for cement: China, Egypt/Algeria and Ukraine,
- for iron and steel: Brazil, China, India, Russia, South Korea, Turkey, Ukraine and United States,
- for chemical (limited to ammonia, ethylene, propylene and methanol): Russia, Saudi Arabia, Ukraine, United States.

For non-ferrous metals industry (limited to aluminium, copper and zinc) the countries analysed are:

- for aluminium: China, Iceland, Kazakhstan, Norway, Russia,
- for copper: Chile, China, Peru, Zambia,
- for zinc: China, Kazakhstan, Namibia, Norway, Russia.

For all industries and countries included in the analysis, production costs are estimated by using a representative sample of facilities. Section 2 provides a description of the research protocol followed and a discussion about the representativeness of the facilities. Section 3 summarises and discusses the results of the detailed analysis that can be found in the four annexes. Section 4 provides some of the conclusions that can be drawn from this study.

2. Research protocol

Although for all industries the JRC draws its conclusion based on an analysis using information at facility level, there is also a top-down analysis of the steel industry using aggregated statistical information. Also for all industries, and in order to avoid any distortion due to differences in capital costs worldwide, we exclude the interest and depreciation of the equipment from the operating cost estimations.

For the iron and steel industry, the facilities covered in this study fall within the class 24.10 of the NACE Rev. 2 classification, that is, the manufacture of iron and steel and ferroalloys. This classification includes all the producers of the upper value chain, even if they do not produce crude steel. In the bottom-up approach, and in order to facilitate the comparability among plants producing the same products, this report uses the cost of the hot-rolled coil as representative of the costs from flat products, and the wire rod as representative of long products.

For the cement industry, the analysis is based on the information at facility level provided by the Global cement database [WBCSD/CSI, GNR, 2014]. The facilities covered in this study fall within the class 23.51 of the NACE Rev. 2 classification. This class includes the manufacture of clinker and hydraulic cements, including Portland, aluminous cement, slag cement and superphosphate cements. At the time of writing, the most recent information released refers to 2012. To provide a glimpse of temporal variability, the estimations are also provided for 2011. The indicators used are: the clinker to cement ratio (indicator 339 in the database), electricity consumption (indicator 3312b), thermal energy consumption (indicator 339a) and percentage of thermal energy from fossil waste, conventional fuel and biomass (indicators 3310, 3311 and 3312). To represent the lowest and highest production cost, the JRC combines the values that produce the lowest and highest costs reported in the benchmarking curves of these indicators.

For the chemical industry, the facilities covered in this study fall within the classes 20.13 and 20.14 of the NACE Rev. 2 classification. They both include the manufacture of chemicals using basic processes, with the difference that 20.13 refers to inorganic compounds, while 20.14 refers to organic compounds.

Steam cracking produces several products including both ethylene and propylene. The analysis follows two approaches: regarding ethylene as the only main product, and regarding both ethylene and propylene as main products.

In the case of propylene, the analysis is also adjusted to the characteristics of the market. Firstly all the facilities producing propylene are compared for the different countries, including the quantities from steam cracking, which are plants already included in the list of ethylene. But due to the differences in quality for the different grades, the analysis distinguishes between two cases, the refinery grade and the polymer and chemical grade together.

For the non-ferrous metals, the facilities covered fall within the following classes of the NACE Rev. 2 classification: 24.42 for aluminium, 24.44 for copper and 24.43 for zinc. The analysis focuses on the primary production route for all three metals. Around 70 % of production cost of the secondary aluminium route is due to the cost of raw material (scrap) and the specific consumption of this route is around 5 % of the primary route. The share of primary copper production is about 80 % globally [ICSG, 2014] and 60 % in Europe [BREF, 2014] and its energy consumption is at least 10 times higher than the secondary production.

For the copper and zinc industries, it should be noted that raw materials costs are not part of the analysis. Mines produce copper concentrates that are sold to copper smelters and refineries for their copper content. The income of mines is mainly a function of the final metal price and the quality of the concentrate. Typically, once treatment charges

(TCs) and refining charges (RCs) are subtracted, the smelter pays to the producer 96-97 % of the metal value contained in the concentrate [Nussir, 2012]. The final price of base metals is decided in international metal exchanges, most importantly the London Metals Exchange (LME), but also the Shanghai Futures Exchange (SHFE) and the Commodity Exchange Inc. (COMEX) based in the United States [ECORYS, 2011; Nussir, 2012]. In conclusion, raw material prices are set in the global market and usually passed on directly to customers. Therefore, they can be excluded from an analysis that is focused on factors such as energy prices, labour costs and to a lesser extent to exchange rates.

In the case of copper, the study distinguishes between smelters (that process concentrates to produce copper anodes) and refineries (that produce copper cathodes from the copper anodes).

2.1 Representativeness of the facilities used for the iron and steel industry

The sample of facilities used to analyse production costs using a bottom-up approach is determined by the facilities covered by the data provider, World Steel Dynamics (WSD). Table 1 represents the number of facilities in the countries of interest, per technology and product.

Table 1: Number of facilities of WSD, per technology and final product, included in the bottom-up analysis for the iron and steel industry

	BF-BOF Flat products (Hot-rolled coil)	EAF Flat products (Hot-rolled coil)	BF-BOF Long products (Wire rod)	EAF Long products (Wire rod)
Brazil	3	0	2	9
China	23	1	40	6
India	3	5	4	1
Japan	11	1	5	6
Russia	4	0	2	3
South Korea	3	2	1	1
Turkey	1	1	1	5
Ukraine	2	0	2	0
United States	14	7	0	7
EU	20	4	6	24
Total	84	21	61	62

When the number of facilities for one product in a country is low, then necessarily the number of facilities of the data provider WSD (in Table 1) will be low. To provide an idea of the degree of coverage of WSD facilities we compare the percentage of the installed capacity of WSD's facilities with the capacity reported in the Plantfacts database in Table 2. The Plantfacts database, prepared by the Steel Institute VDEh, comprises details of iron and steel production facilities worldwide (VDEh, 2014). At present, the Plantfacts database contains over 350 000 single entries covering more than 12 500 facilities.

Table 2: Percentage of the total installed capacity of WSD facilities in the countries studied

	BF-BOF Hot-rolled coil	EAF Hot-rolled coil	BF-BOF Wire rod	EAF Wire rod
Brazil	67 %	NA	100 %	100 %
China	58 %	16 %	91 %	100 %
India	54 %	100 %	95 %	97 %
Japan	86 %	23 %	97 %	100 %
Russia	95 %	0 %	90 %	100 %
South Korea	88 %	70 %	78 %	97 %
Turkey	51 %	36 %	100 %	100 %
Ukraine	96 %	NA	86 %	NA
United States	100 %	45 %	NA	100 %
EU	92 %	34 %	100 %	70 %

'NA' means that there is no facility in that country and no product, neither in Plantfacts nor in WSD. Therefore, the numbers that can be read in Table 1 of just four, three and two facilities in Russia, South Korea and Ukraine producing hot-rolled coil represent 95 %, 88 % and 96 % of the installed capacity of hot-rolled coil in those countries.

Table 3 provides an overview of the representativeness of these facilities. This table gives the total capacity installed (from the Plantfacts database) and the capacity of the plants included in WSD data. The WSD plants account for 75 % of the corresponding capacity in the countries under study.

Table 3: Capacities in the Plantfacts database and in the facilities considered in WSD countries

In the countries studied	Flat products		Long products		Total
	BF-BOF Hot-rolled coil	EAF Hot-rolled coil	BF-BOF Wire rod	EAF Wire rod	
Plantfacts	495 Mt	99.2 Mt	69 Mt	23 Mt	687 Mt
WSD	377.8 Mt	43.8 Mt	64 Mt	23 Mt	517 Mt
Percentage	76 %	44 %	93 %	100 %	75 %

On the other hand, the top-down approach starts from the detailed information about energy consumption per industry from INDSTAT statistics [UN, 2014]. Although this alternative approach can be useful in analysing energy consumption per country and the kind of fuel, it makes no distinction among technologies and products.

2.2 Representativeness of the facilities used for the cement industry

The indicators used for Algeria and Egypt correspond to those reported for Africa in the Global cement database [WBCSD/CSI, GNR, 2014]. The North African plants (Morocco 13, Algeria 4, Tunisia 2 and Egypt 10) represent 40 % of all African plants in the database (68). Therefore it is plausible to assume that the performance of African plants is similar to the corresponding performance of North African plants. We also used the overall performance of the plants of countries of the Commonwealth of Independent States (CIS) to account for the performance of Ukrainian plants. In this case, the database contains almost half of the Ukrainian plants (Table 4). In terms of numbers, Ukrainian plants represent almost 30 % of the 21 plants of CIS countries included in the database.

Table 4: Number of facilities and degree of coverage of the Global cement database on CO_2 and energy information 'Getting the Numbers Right' [WBCSD/CSI, GNR, 2014; TPL, 2013]

	Number of plants in the Global cement database	Total number of plants in the country/region	Coverage (% of cement production, 2012)	Production Capacity Mt cement
Africa	68	183	44	235
Algeria	4	14	21	20
Egypt	10	23	59	65
CIS	21	96	21	134
Ukraine	6	13		19
China	78	3 900	4	2 950
EU	303	341	94	317

The average of the clinker to cement ratio in China has been taken from the Chinese almanac [China almanac, 2011], and the lowest and highest values have been assumed similar to the lowest and highest values in the facilities/countries under study.

2.3 Representativeness of the facilities used for the chemical industry

The analysis is based on information at facility level provided by IHS Chemical in the form of a database [IHS, 2014]. Table 5 shows the number of facilities included in the analysis. The database has 100 % coverage of the countries included in the study. Globally, the total installed capacity for ammonia in 2013 was 214 Mt_{NH3}, with the five countries of interest covering 23.5 %, while in the case of methanol the countries of interest represent 15.9 % of the 98.3 Mt_{meth} installed globally. In the case of ethylene and propylene the global coverage of the five countries is 46.7 % and 39.3 % respectively (154.4 $Mt_{ethylene}$ and 45.0 $Mt_{propylene}$ global installed capacity).

Table 5: Number of facilities per product included in the chemical industry analysis in 2013

	Ammonia	Methanol	Ethylene (1)	Propylene		
				Refinery grade	Chemical/Polymer grade: All	Chemical/Polymer grade: Without steam crackers
EU	48	5	50	50	91	43
Russia	28	10	14	4	16	6
Saudi Arabia	6	8	15	1	20	7
Ukraine	9	1	2	-	1	-
United States	25	5	41	75	72	38
Total	116	29	122	130	200	94

(1) Besides ethylene these plants are also producing other co-products, including propylene in most cases.

In the database some information depends on facility, process or country. For each facility, the nominal capacity, as well as the process used, is known. The operating rate and all prices depend on the country in which the facility is located. Lastly, consumption, production and number of operators needed depend on the process used by the facility.

2.4 Representativeness of the facilities used for the non-ferrous metals industry

2.4.1 Representativeness of the facilities used for the aluminium industry

In the bottom-up approach we have included all operating aluminium smelters [Pawlek, 2014] in the countries of interest (Table 6). One of the countries initially considered (Saudi Arabia) was disregarded because its only plant (Ras Al Khair, with a capacity of 0.74 Mt) was under construction during 2012 and only entered in operation by the end of 2013 [MA'ADEN, 2015]. Iceland and Norway have been added to the initial list to include two of the three countries with highest exports to the EU (the first, Russia, was originally on the list).

Table 6: Capacity and number of aluminium smelters in operation or in construction in 2013

	Number of smelters	Number of smelters in construction	Total capacity Mt
China	119	19	26.87
Iceland	3	1	0.65
Kazakhstan	1	0	0.24
Norway	7	0	1.33
Russia	7	2	3.56
EU	16	0	3.11

2.4.2 Representativeness of the facilities used for the copper industry

The bottom-up approach is based on information at facility level provided by Wood Mackenzie in a database [Wood Mackenzie, 2015]. The database covers more than 90 % of total primary production from copper smelters worldwide in 2013 and about 93 % of copper production in China. It includes information directly from plants and is one of the most detailed commercial databases containing actual data. The tentative countries in the initial list included China, Russia, Kazakhstan and Saudi Arabia/Qatar. However, since there is no information available about all of them, we replace Russia, Kazakhstan and Saudi Arabia/Qatar by Chile, Peru and Zambia from which the EU imports copper cathodes [Eurostat, 2015].

Table 7: Number and capacity of copper smelters and refineries in operation in 2012

	Copper smelters		Copper refineries	
	Number	Capacity (Mt)	Number	Capacity (Mt)
EU	8	2.5	12	2.7
Chile	7	2.0	3	1.1
China	13	4.4	16	5.1
Peru	1	0.4	1	0.3
Zambia	3	0.6	2	0.5

Table 7 shows the number of facilities included in the analysis. The differences between 2012 and 2013 were that in China a new smelter started operating while a copper refinery was closed down and another started. In both cases the total installed capacity in China grew by about 0.5 Mt.

2.4.3 Representativeness of the facilities used for the zinc industry

As in the case of copper, the bottom-up approach is based on information from the Wood Mackenzie database [Wood Mackenzie, 2015]. The global coverage of the database is over 80 %, including all of China with the exception of the very small smelters, resulting in about 65 % total production coverage. Table 8 shows the number of smelters considered in this study. The only difference between 2012 and 2013 was that a smelter in Bulgaria closed down.

Table 8: Number and capacity for zinc smelters in 2012 and 2013

	Number	Capacity (Mt)
EU	11	2.0
China	6	1.0
Kazakhstan	2	0.3
Namibia	1	0.2
Norway	1	0.2
Russia	2	0.3

3. Discussion of the results

3.1 Results for the iron and steel industry

Figure 1 summarises the overall energy costs for the whole industry due to fossil fuel consumption (either consumed as reductants or as thermal energy) and also due to electricity consumption. These values come from a top-down approach and aggregate the overall consumption, irrespective of the value of the final product and the technology used.

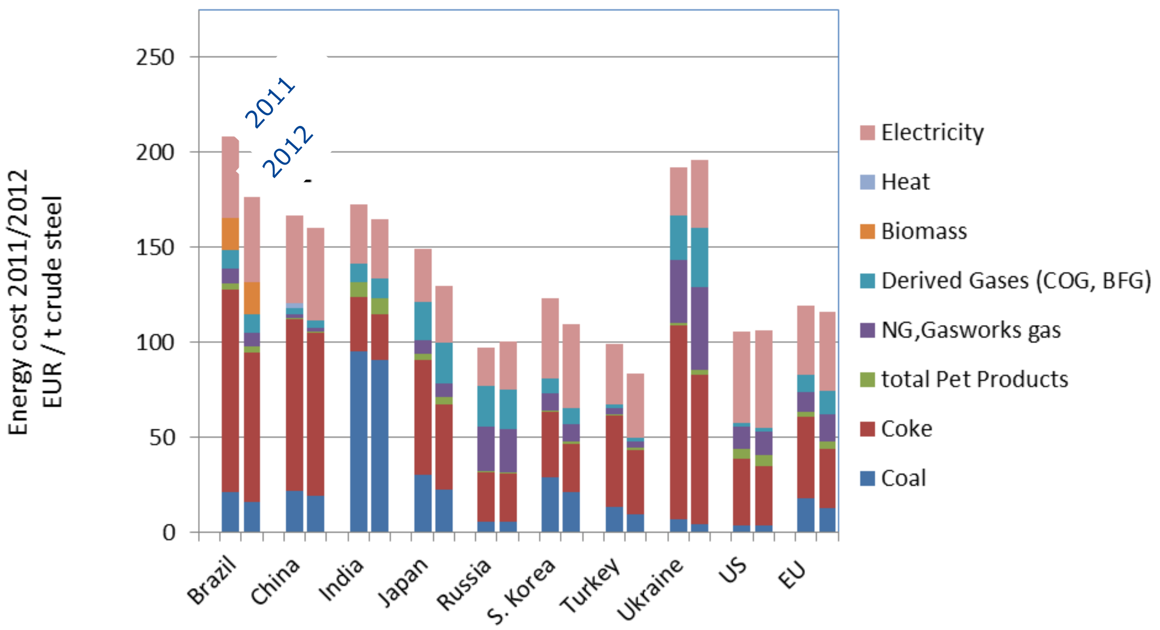

Figure 1: Energy costs in the iron and steel industry for 2011/2012 (using the top-down approach)

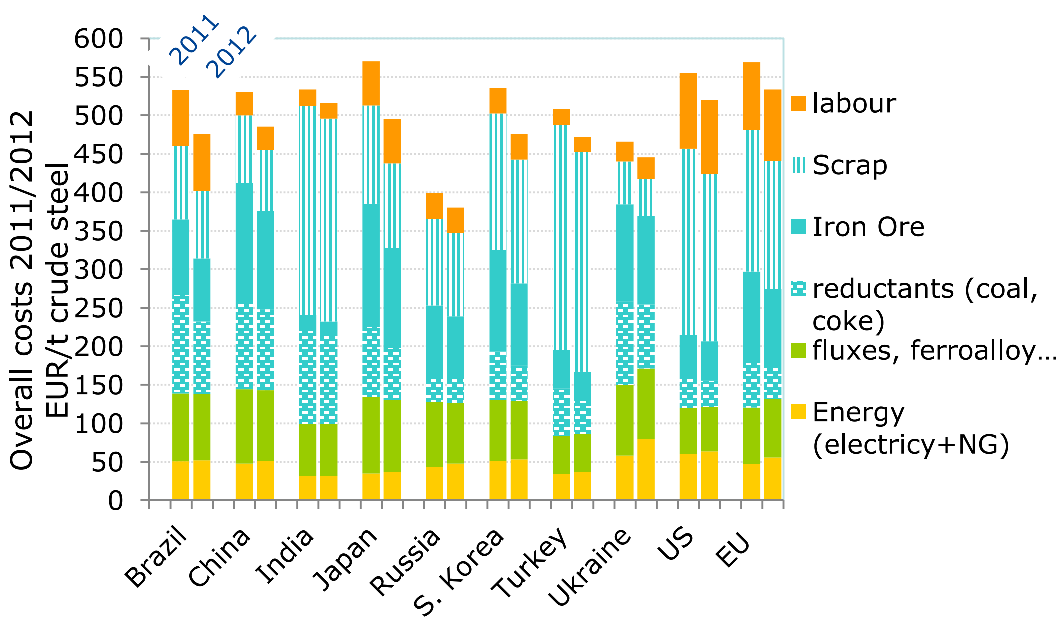

Figure 2: Total production costs per tonne of crude steel (EUR/t crude steel, using the top-down approach)

Figure 2 incorporates the rest of the costs considered in the top-down approach using the same breakdown as the data provider World Steel Dynamics (whose cost-curve information is the core of the bottom-up analysis that follows).

If we exclude the labour costs from the comparison, the costs in the EU (only including raw materials, other and energy costs) are higher than the costs in Brazil and Russia, lower than the Indian costs and in line with the rest of the competitors.

Since the top-down analysis does not distinguish between technologies or products, in order to compare homogeneous products and routes, it is necessary to use a bottom-up approach focusing on the possible combinations of long and flat products (hot-rolled coil and wire rod) coming from the integral route (BF-BOF) and the recycling route (EAF). Figure 3 to Figure 6 show the resulting cost curves.

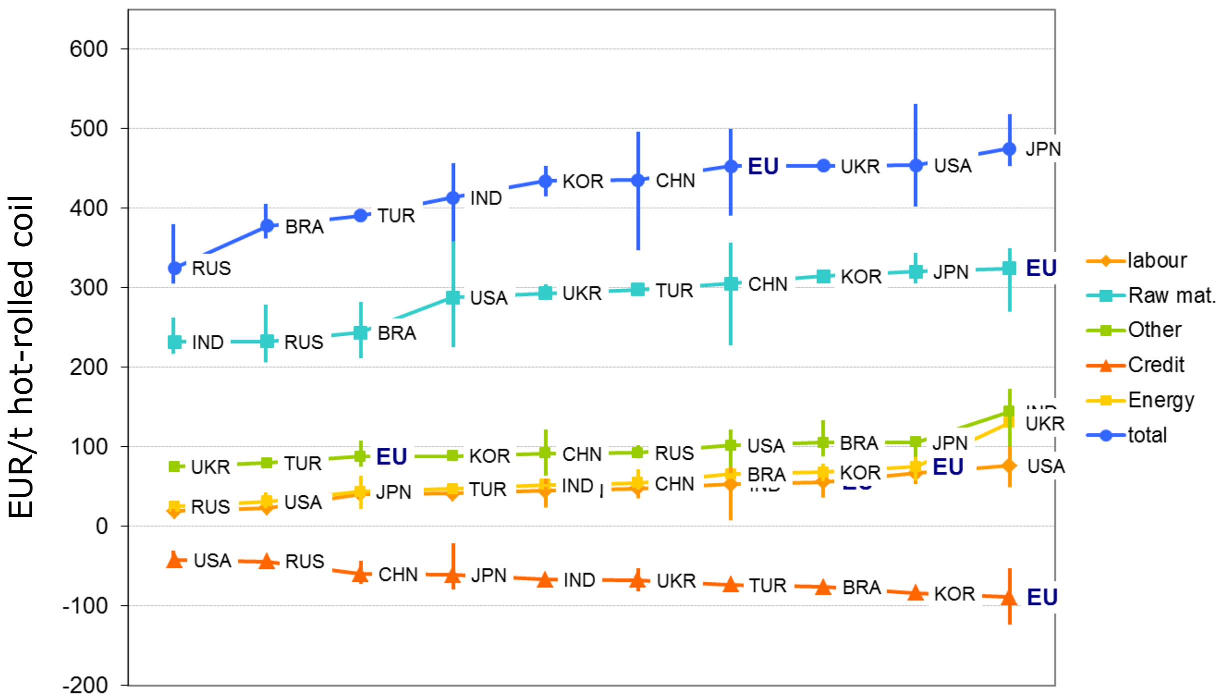

Figure 3: Average cost curves in 2013 of hot-rolled coil in the integrated route (BF-BOF)

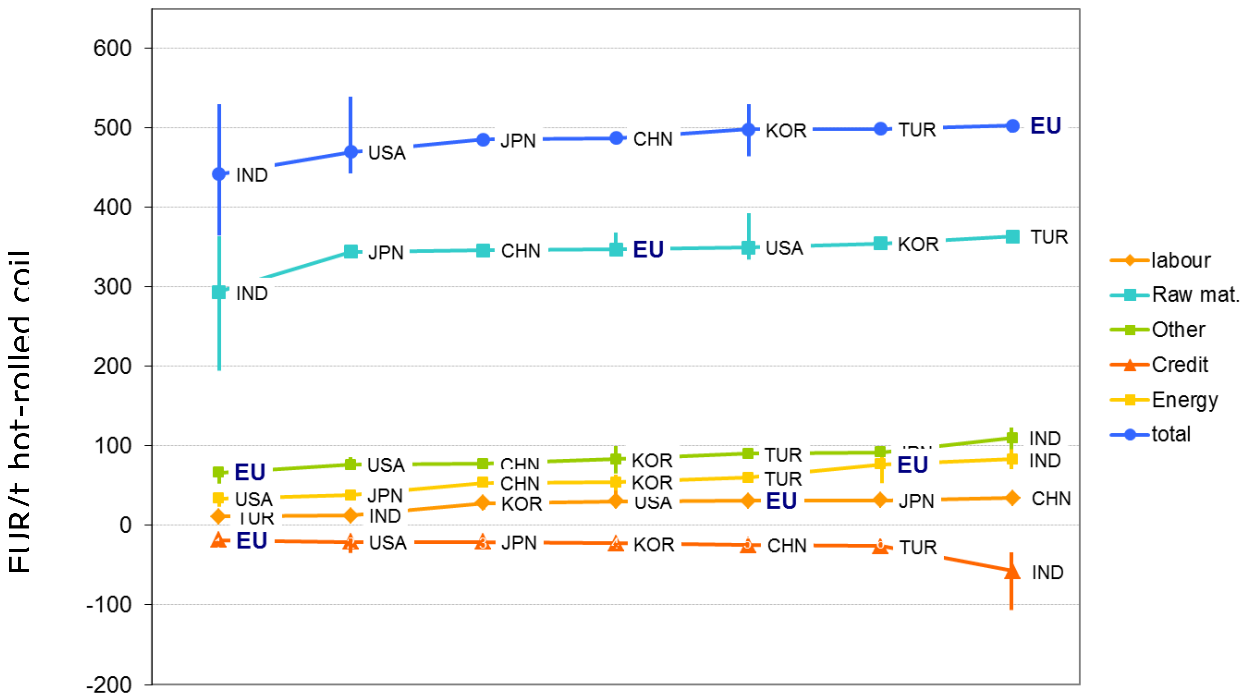

Figure 4: Average cost curves in 2013 of hot-rolled coil in the recycling route (EAF)

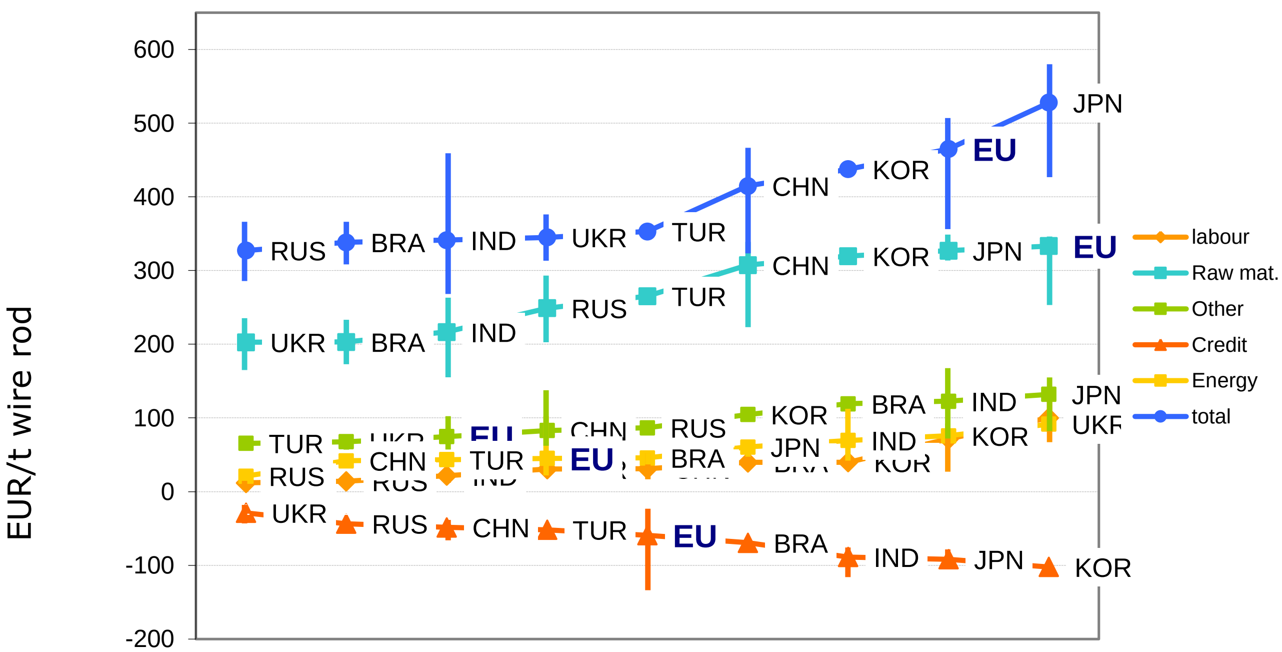

Figure 5: Average cost curves in 2013 of wire rod in the integrated route (BF-BOF)

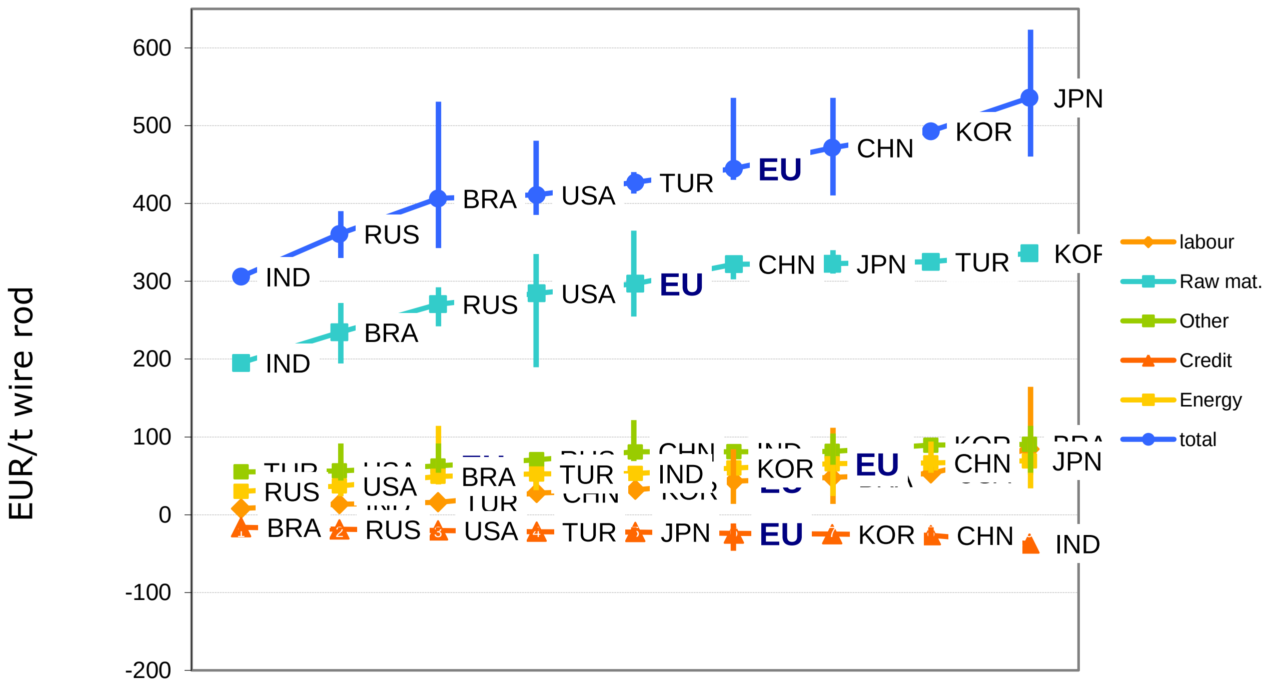

Figure 6: Average cost curves in 2013 of wire rod in the recycling route (EAF)

This report includes the analysis of production cost of long products (wire rod) using the integrated route (BF-BOF) because the global installed capacity of long products from BF-BOF triples the capacity from the recycling route (EAF) (Figure 5). Also, flat products from the recycling route (results in Figure 4) are gaining market share, and therefore, are also included in the analysis.

When reading the cost of the natural gas and electricity in Figure 3 to Figure 6, one has to keep in mind that the industry, at least in the EU, makes good use of their waste gases (coke oven gas, blast furnace gas and basic oxygen gas). This fact is reflected in the term 'credit' that collects the savings for the industry of recycled scrap and self-power generation. More concretely, in the EU around 80 % of power consumption is generated 'in situ'.

All in all, if we exclude the labour costs, the overall results (shown in Figure 2) of the top-down approach agree with Figure 3 to Figure 6, revealing Japan and Russia as the countries with the highest and lowest production costs respectively. In Figure 3 and Figure 6 there are three countries with higher production costs than the EU.

In spite of the fact that Figure 4 shows the EU as the region with the highest production costs for hot-rolled coil from the EAF, for all countries, except India, production costs are quite similar and have low variability (the curve of total production costs is the flattest of all similar curves of Figure 3 to Figure 6). Also, the variability in the country with the lowest production costs (India) encompasses the production costs of the rest of the countries.

It is also remarkable that the highest contribution to the cost for steel products from the EAF route (Figure 4 and Figure 6) is the term 'raw materials'. In the case of the EAF, the raw materials correspond to scrap. On the other hand, in the integrated route (Figure 3 and Figure 5), the term 'raw materials' also includes coal, coke and raw iron. However, it can be seen that the contribution to the total cost of scrap in the EAF is always higher than the contribution of coal, coke, raw iron and scrap in the integrated route.

For both products, flat and long, and for almost all countries, the total cost in 2013 for the EAF route is higher than in the BF-BOF route (the total cost of Figure 4 is always higher than in Figure 3, and again, in Figure 6 it is almost always higher than in Figure 5). As previously mentioned, this is due mainly to the scrap price in 2013. This observation is also valid even for the long products from the BF-BFO route, although the products by this route have a small presence in the EU.

3.2 Results for the cement industry

Figure 7 summarises the energy costs of the fuel mix used in the countries under study. This figure combines the effect of the fuels price and the performance of the industry in each country. For example, although the thermal performance in Algeria and Egypt is quite similar, their energy costs are quite different due to the different fuel used: natural gas in Algeria and fuel oil in Egypt.

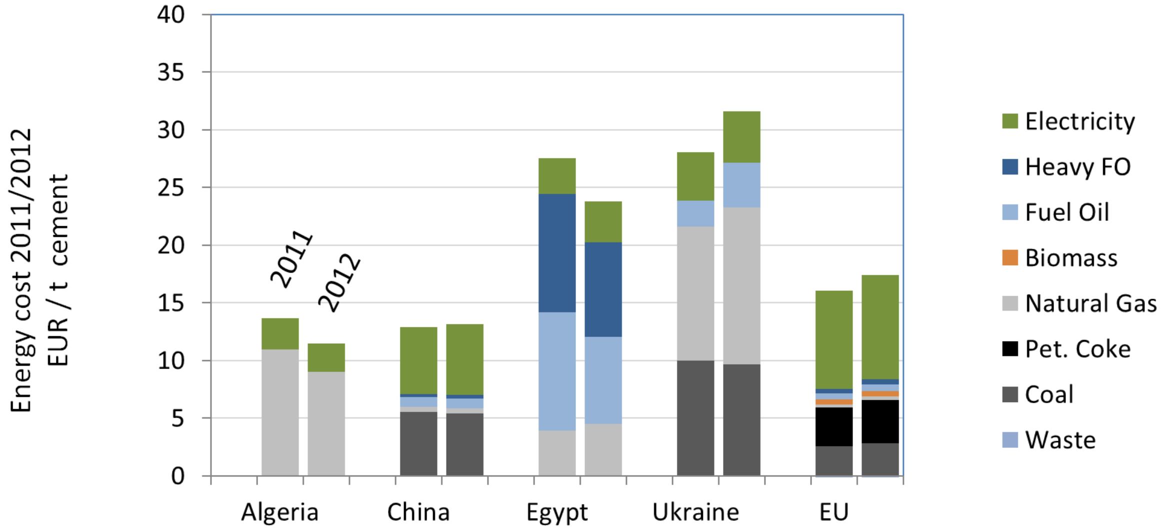

Figure 7: Energy costs of the fuel mix used in the cement industry in 2011/2012

The cost of the thermal energy consumed by the EU industry is quite similar to the value of the country with lowest production costs (China), however, when adding the EU electricity price, the total EU energy costs are the third highest (out of the five countries under study), though still well below Ukrainian and Egyptian energy costs.

When adding the rest of the costs — raw materials, labour and other costs — the position of the EU industry worsens, leaving the EU total final cost in 2012 between the Egyptian and Ukrainian costs (Figure 8).

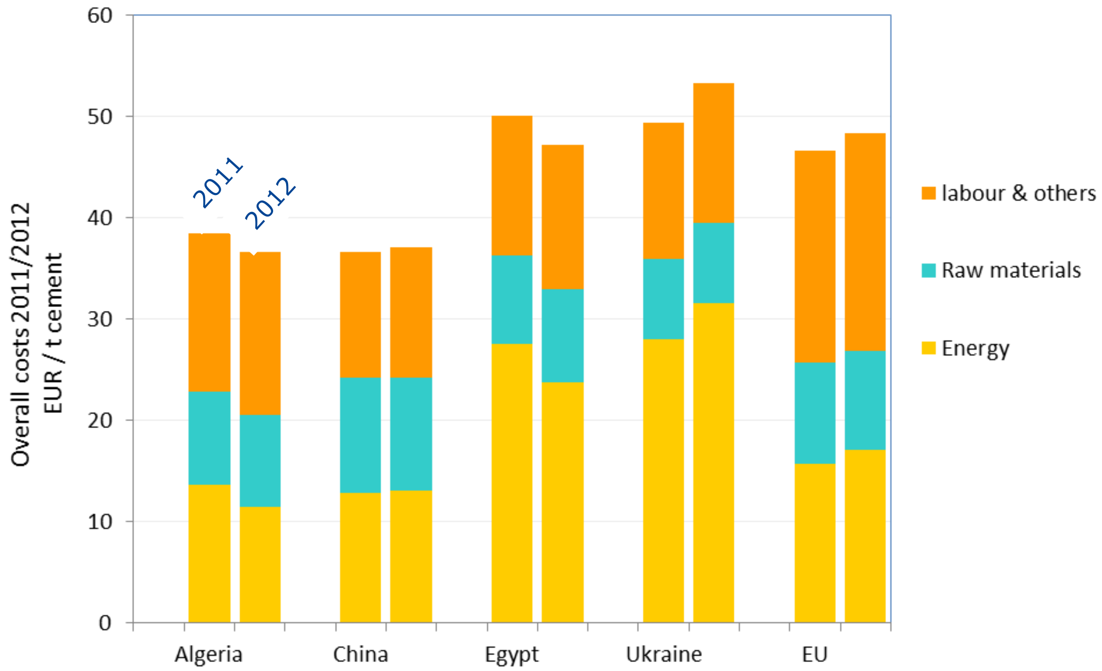

Figure 8: Summary of the cement industry costs in 2011 and 2012

Figure 9 represents the specific costs in each country. Each vertical line joins the minimum and maximum cost estimated for each country (according to their different performances and prices). The values of the average total costs in Egypt (47 EUR/t), the EU (48 EUR/t) and Ukraine (53 EUR/t) are quite similar. However, the variability between the best and worst performer is much higher in Egypt than in the EU and Ukraine; this is due to the high cost of the main fuel used in Egypt (fuel oil).

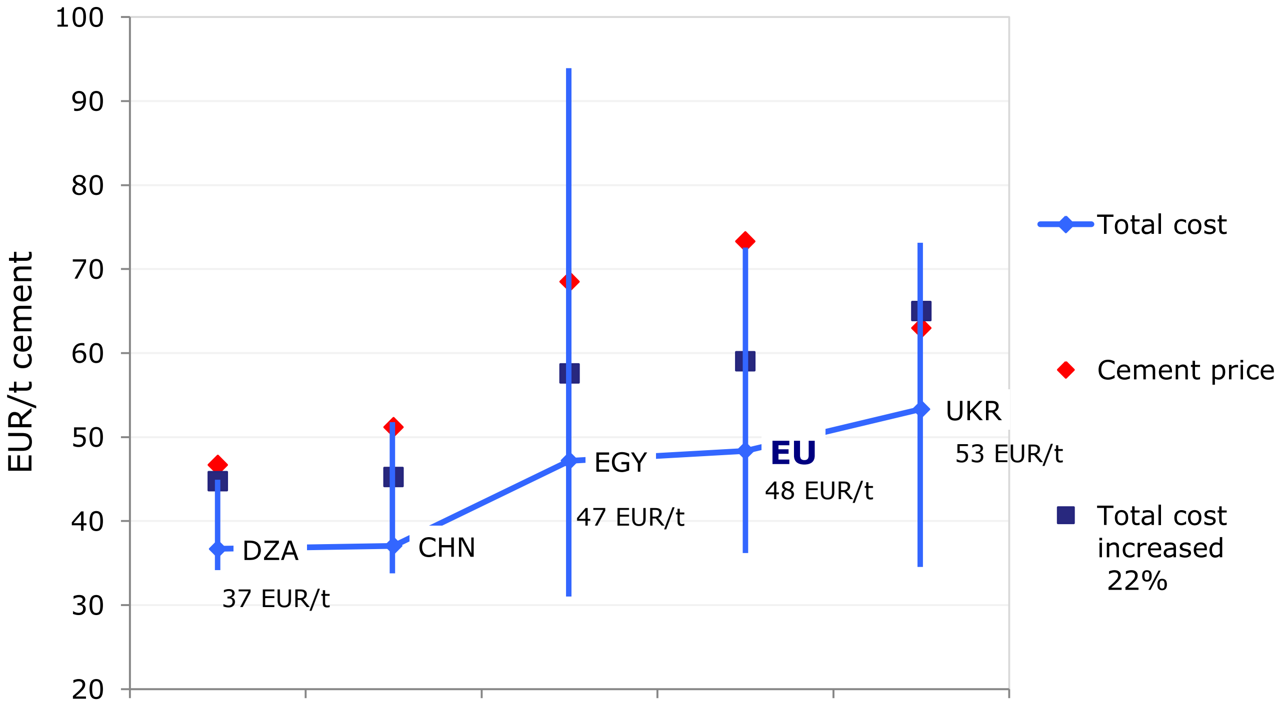

Figure 9: Average cost curve of cement production in 2012, cement price and intervals encompassing the maximum and minimum estimated costs

The average costs of the Chinese and Algerian production (around 37 EUR/t for both countries) are clearly lower than in the rest of the countries. However, the lowest production costs across all countries show small variability (from 30 to 36 EUR/t), meaning that in all countries the most competitive producers are able to produce cement with relatively similar costs.

Note that the costs described are the main components of ex-factory prices; they do not include shipping, handling, taxes or customs. These costs exclude additional components of the price such as the capital costs (interest and depreciation) and benefit. Transport costs, not included in this analysis, are around EUR 10 per tonne of cement per 100 km by road and around EUR 15 to cross the Mediterranean Sea [Hourcade et al., 2007].

According to the BREF of the industry [BREF, 2013], the profit of the cement industry is around 10 % as a proportion of turnover (on the basis of pre-tax profits before interest repayments). Also according to [Lasserre, 2007], the depreciation cost represents around 12 % of the total cost. Therefore, an increase of around 22 % or our cost estimation could roughly estimate the final cement price when considering some components excluded in this analysis (capital cost and profit), as shown in Figure 9. This figure also incorporates the cement prices observed. In 2012 the price of the production in the EU was 73.3 EUR/t [Eurostat, 2014a]. The latest prices (in 2011) reported in the INDSTAT database [UN, 2014] were 51.2 EUR/t in China and 63.0 EUR/t in Ukraine. In 2012, the Global Cement Report [TPL, 2013] mentions prices of 46.7 EUR/t in Algeria and 68.5 EUR/t in Egypt.

3.3 Results for the chemical industry

3.3.1 Results for the ammonia industry

Figure 10 summarises the overall average costs for the ammonia industry. Costs for ammonia production are very dependent upon the cost of feedstock. Since the vast bulk of ammonia is produced from natural gas, the cost of natural gas is the decisive factor determining the cost of producing ammonia. Natural gas prices vary significantly from region to region. The EU, as well as the other countries, cannot compete with Saudi Arabia, where natural gas prices are around one tenth of the price in the EU. For the EU, the total average costs in 2013 amounted to 336.8 EUR/t, with 85 % of it corresponding to feedstock costs, while in the case of Saudi Arabia and the United States the feedstock costs only account for 34 % and 67 % respectively.

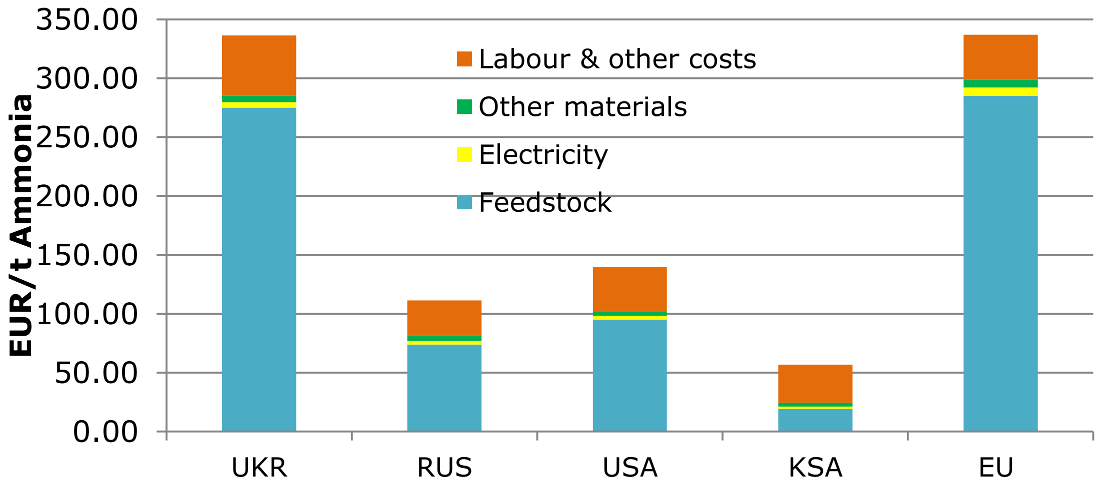

Figure 10: Summary of total costs for the ammonia industry in 2013

On the other hand, labour and other costs, which include labour overheads, property taxes and maintenance costs, account for 11 % of the overall costs in the EU, 15 % in Ukraine and 27 % in Russia. Although labour is almost 7 times cheaper in Ukraine than in the EU, the productivity of Russia and Ukraine is almost 3 times lower than in the EU, the United States and Saudi Arabia.

In the case of ammonia, the most common process is steam reforming of natural gas. However, in the United States, the large variability of feedstock costs (Figure 11) is explained by the coexistence of different technologies for ammonia production.

Labour is the only component of the costs where there are noticeable variations. These variations are due to the different size of the plants, which highly influences the labour and capital costs (the latter affecting the property taxes and the maintenance costs). In the case of ammonia production costs in the United States, the large variability is due to both labour costs and feedstock costs, while in the case of the EU the variability is due to the fact that it consists of several countries with different prices and productivities.

In 2013 the average price of ammonia in the Gulf Coast of the United States was about 450 EUR/t [USGS, 2014], and the price in western Europe in April 2013 was reported to be around 350 EUR/t [Market Realist, 2013]. These prices can be used to give an idea of the components of the costs.

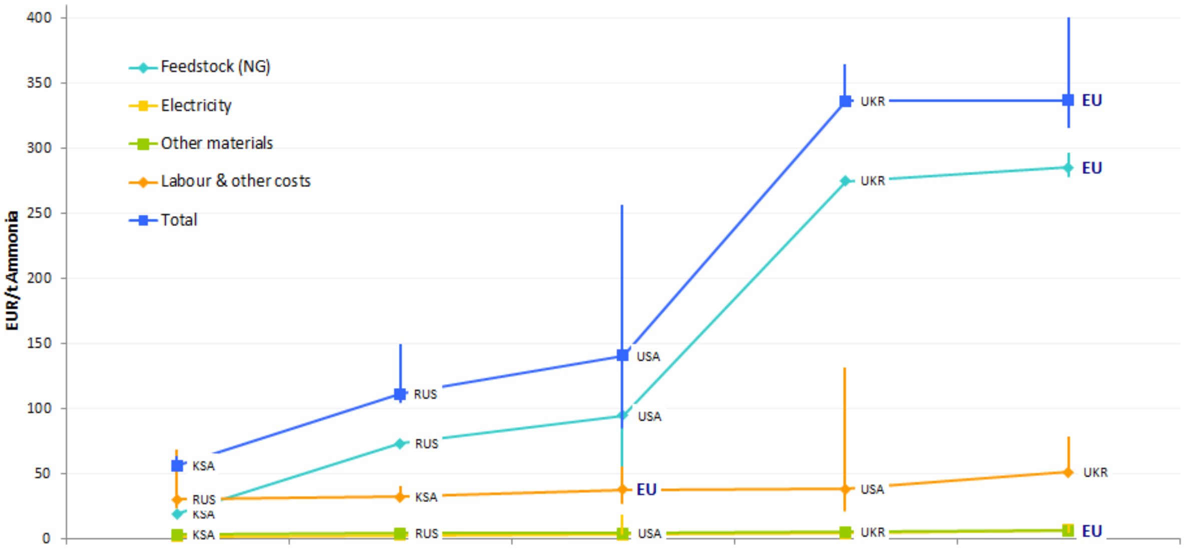

Figure 11: Average cost curves of ammonia production in 2013 and intervals encompassing the maximum and minimum estimated costs

3.3.2 Results for the methanol industry

Figure 12 depicts the overall average costs for the methanol industry. The costs for methanol production are very dependent upon the cost of feedstock. In the countries or regions where feedstock is locally produced (e.g. in the Middle East and in Russia), the production costs are much lower. For the EU industry the total average cost of methanol production in 2013 was 408.2 EUR/t, of which 85 % was due to feedstock costs, while in the case of Saudi Arabia feedstock costs represented only 36 % of total costs.

For this product and in the EU, electricity seems to be a more important cost component than in the case of ammonia, but this is the result of the fact that the industry is almost entirely localised in Germany (90 % of the EU methanol industry is located in Germany).

Germany is the country with the second most expensive electricity in the EU, after Italy, with the price for band ID ([2]) being 1.5 times higher than the one in the Netherlands, where the rest of the EU methanol industry is located [Eurostat, 2014b].

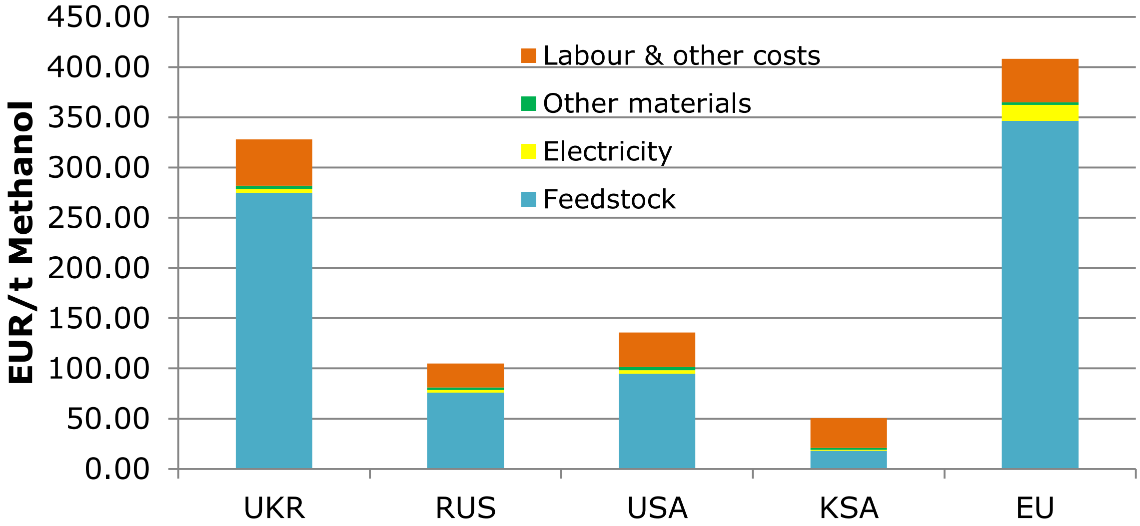

Figure 12: Summary of the total costs for the methanol industry in 2013

The minimum and maximum costs in Figure 13 are due to both the different technologies available and the prices among the countries. It is obvious that the feedstock cost is the decisive factor for the total cost, as in the case of ammonia. Although the EU does not have much difference in the costs for the other components, the differences in feedstock are noteworthy. The high variability in the total cost in Russia is due to the big difference in the feedstock costs between the processes using natural gas and heavy fuel oil.

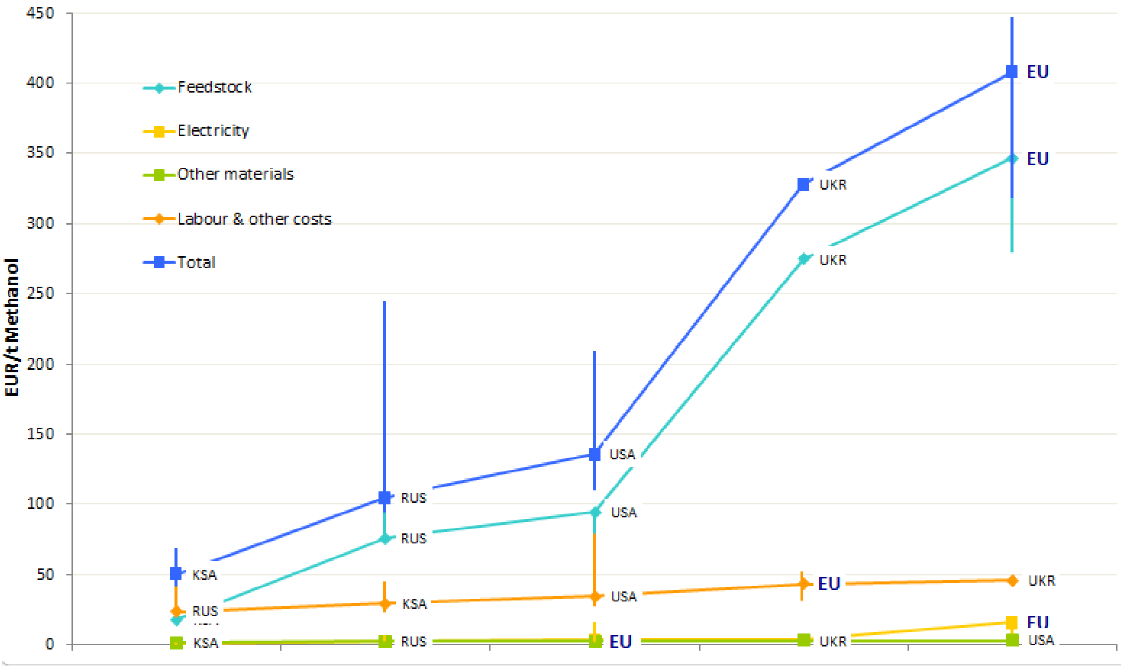

Figure 13: Average cost curves of methanol production in 2013 and intervals encompassing the maximum and minimum estimated costs

([2]) Band ID: Annual consumption between 2 000 and 20 000 MWh.

The price of methanol in the EU in 2013 was 370-450 EUR/t, while in Asia the price ranged between 325 and 414 EUR/t and the non-discounted reference price was between 362 and 475 EUR/t [Methanex, 2014]. It is obvious from the comparison of costs and prices of methanol, as well as the results shown in Figure 12, that in the EU the methanol industry faces strong competition. The main change taking place in Europe is the development of biomethanol. There is already a plant in the Netherlands producing methanol through both routes: traditional and biogas process. This last process allows production of syngas from crude glycerine that is the by-product of biodiesel [Hamm & Voncken, 2013]. A techno–economic analysis of this process has concluded though that currently biomethanol cannot compete with methanol without the help of subsidies or regulations. Biomethanol can become more attractive if the price of natural gas exceeds 0.45 EUR/Nm^3 or if glycerol is available at less than 90 EUR/t [Balegedde Ramachandran et al., 2013].

3.3.3 Results for the ethylene industry

Ethylene is produced via steam cracking, but it is not the only product of the process. Therefore, there is an additional component in the total costs: credits due to the value of co-products obtained during the production of ethylene. Figure 14 shows the overall average costs of steam cracking per tonne of ethylene.

A major feature of the ethylene industry, and dissimilar to the ammonia and methanol industries, is the variety of feedstocks that can be used in steam cracking. Naphtha has historically been an expensive feedstock in North America, in contrast to domestic natural gas liquids (primarily ethane and propane), and as a result, a big part of the American steam cracking industry is based on these latter fuels as feedstock. This is also the case in Saudi Arabia. In contrast, ethylene producers in the EU and Japan favour petroleum liquid feeds. Generally ethane feedstocks generate small quantities of co-products, while naphtha- and distillate fuel oil-based crackers have high quantities of co-products. This difference between feedstocks can be seen in both Figure 14 and Figure 15.

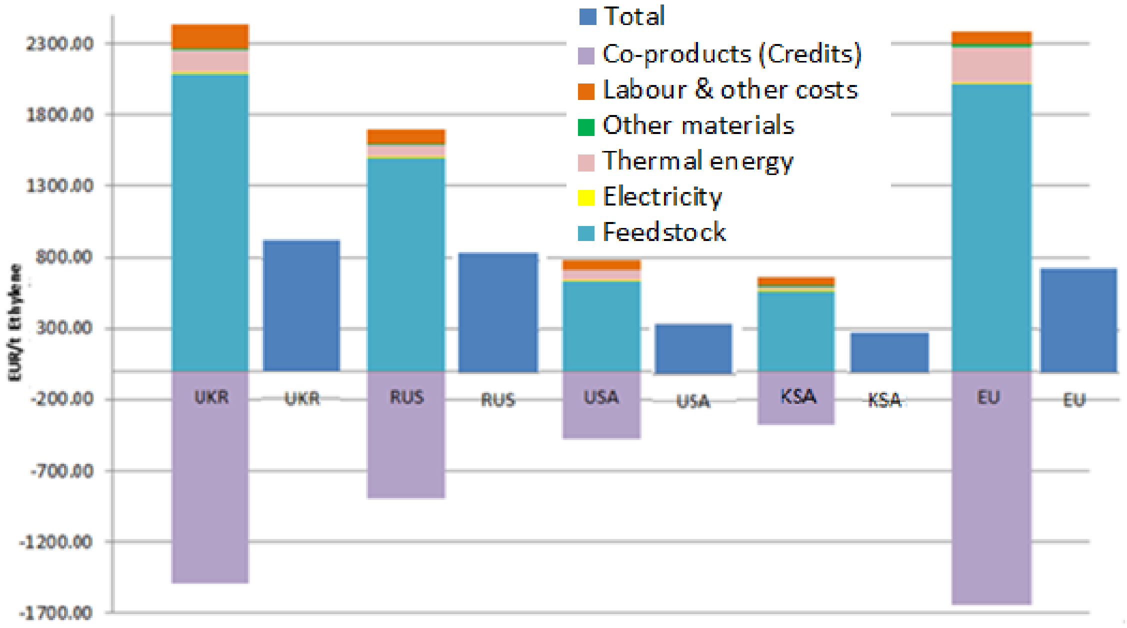

Figure 14: Summary of total costs for steam cracking in 2013 per tonne of ethylene

In Figure 15 the total costs (dark blue curve) are lower than the feedstock costs (light blue curve) due to the credits. The high prices of fuels in the EU mean high feedstock costs, but also high credits. Thus, the total costs in the EU are lower than in Russia and Ukraine.

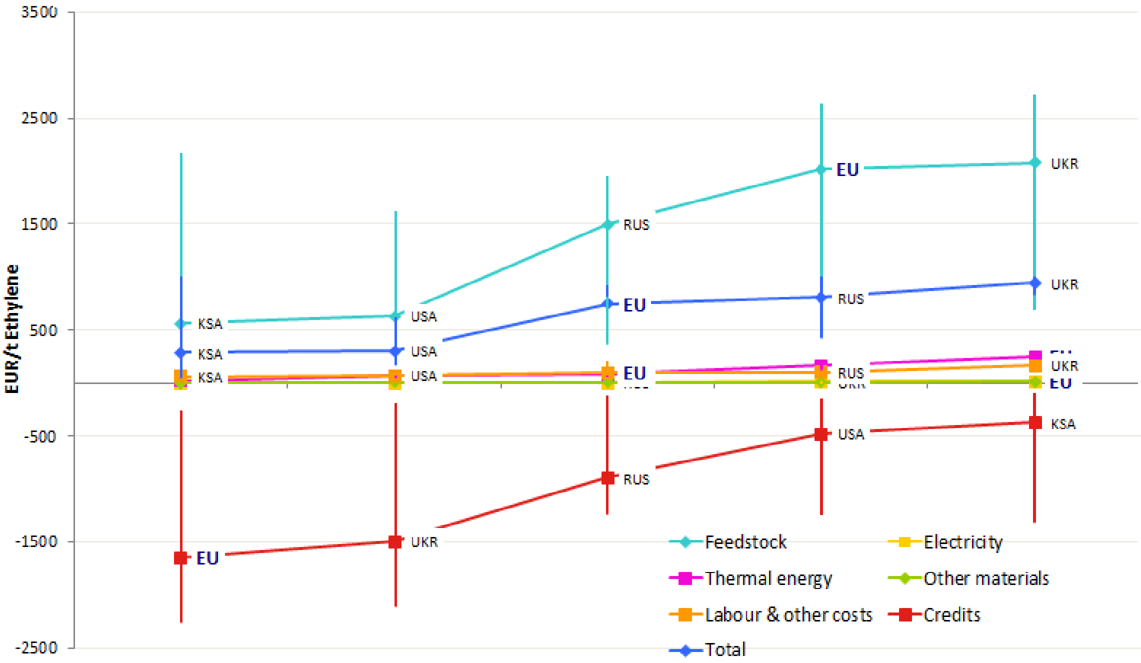

Figure 15: Average cost curves of ethylene production in 2013 and intervals encompassing the maximum and minimum estimated costs

Consumptions and costs can be expressed in various ways, depending on what is considered as the main product. Figure 14 and Figure 15 are based on assuming ethylene as main product of the steam cracking process. But the co-products of the process also include propylene. Thus the same analysis is done by considering both ethylene and propylene as the main products, as mentioned already in Section 2. Figure 16 and Figure 17 summarise the results in this latter case.

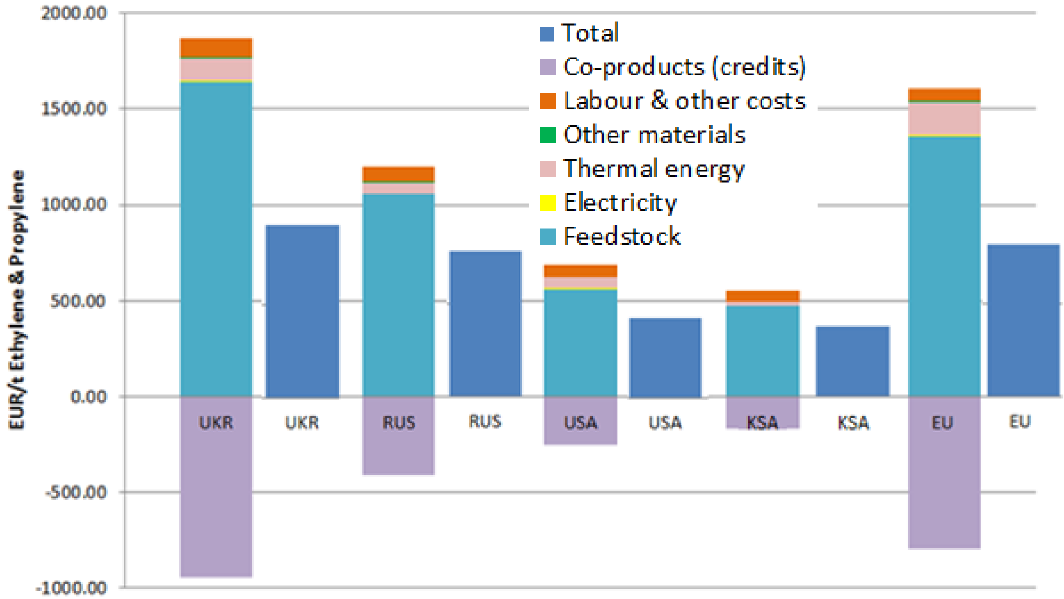

Figure 16: Summary of total costs for steam cracking in 2013 per tonne of ethylene and propylene

Since total olefin production is higher than when producing only ethylene, in this case the six components of the costs will be lower than previously, including credits. In the EU overall costs amount to 748.4 EUR/t when considering ethylene as the only product, or 816.2 EUR/t when both olefins are considered as products. In September 2013 global ethylene prices reached about 973 EUR/t following changes in the price of naphtha [Platts, 2015a].

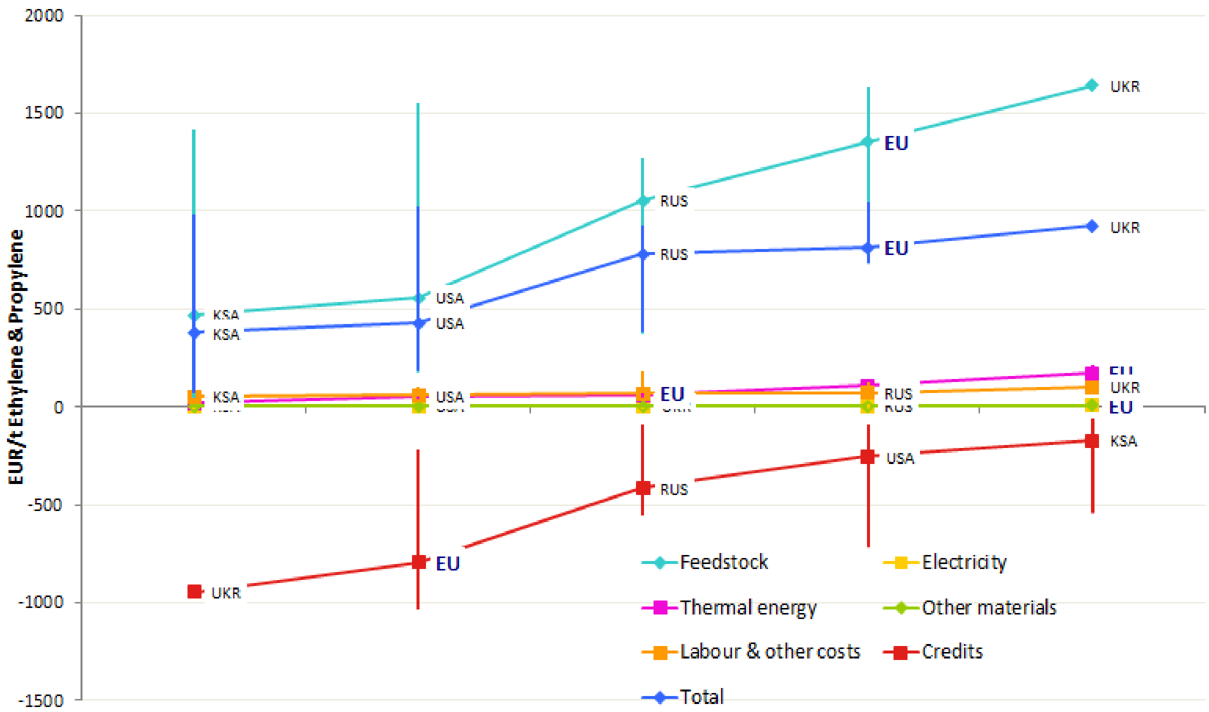

Figure 17: Average cost curves of steam cracking for combined ethylene and propylene production in 2013 and intervals encompassing the maximum and minimum estimated costs

3.3.4 Results for the propylene industry

Propylene can be produced via several processes: steam cracking, fluid catalytic cracking (FCC) or 'on-purpose' propylene processes. Regardless of process, the final product is the same and it is undistinguishable in the market. As a result, the costs of all processes are grouped together (Figure 18 and Figure 19).

In most countries propylene is produced from all types of processes. Ukraine is the only exception, as propylene is produced only by steam cracking. As propylene is only a co-product of this process and not a main product, propylene production costs in Ukraine are higher than in the rest of the countries.

In general, the main factor of total costs is feedstock, but due to the variety of potential feedstocks, the industries in the different countries are adjusted to the cheapest available choice. As a result there are no remarkable differences in feedstock costs among the analysed countries.

In 2013, total average costs in the EU amounted to 784 EUR/t for propylene of all grades, while in Saudi Arabia, which had the lowest production costs in all other products, and Russia, which is one of the main countries from which the EU is importing products, total average costs were 781 EUR/t and 743 EUR/t respectively. In September 2013 the price of global propylene for polymers reached 1 030 EUR/t [Platts, 2015b].

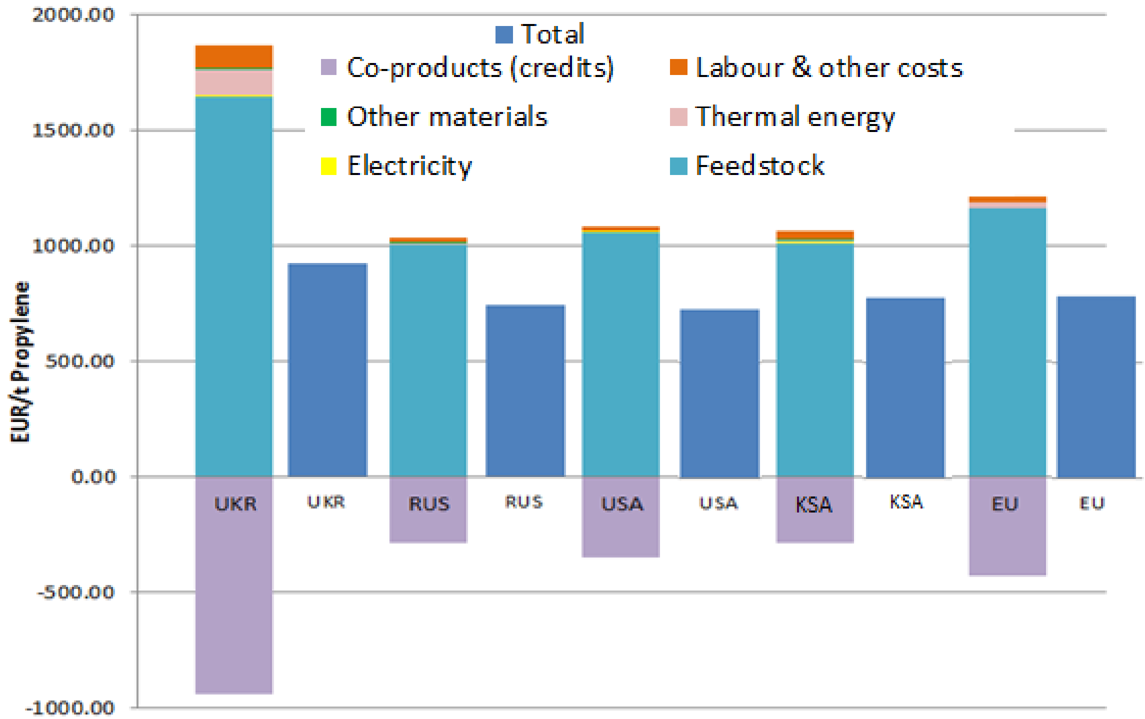

Figure 18: Summary of total costs for the propylene industry in 2013

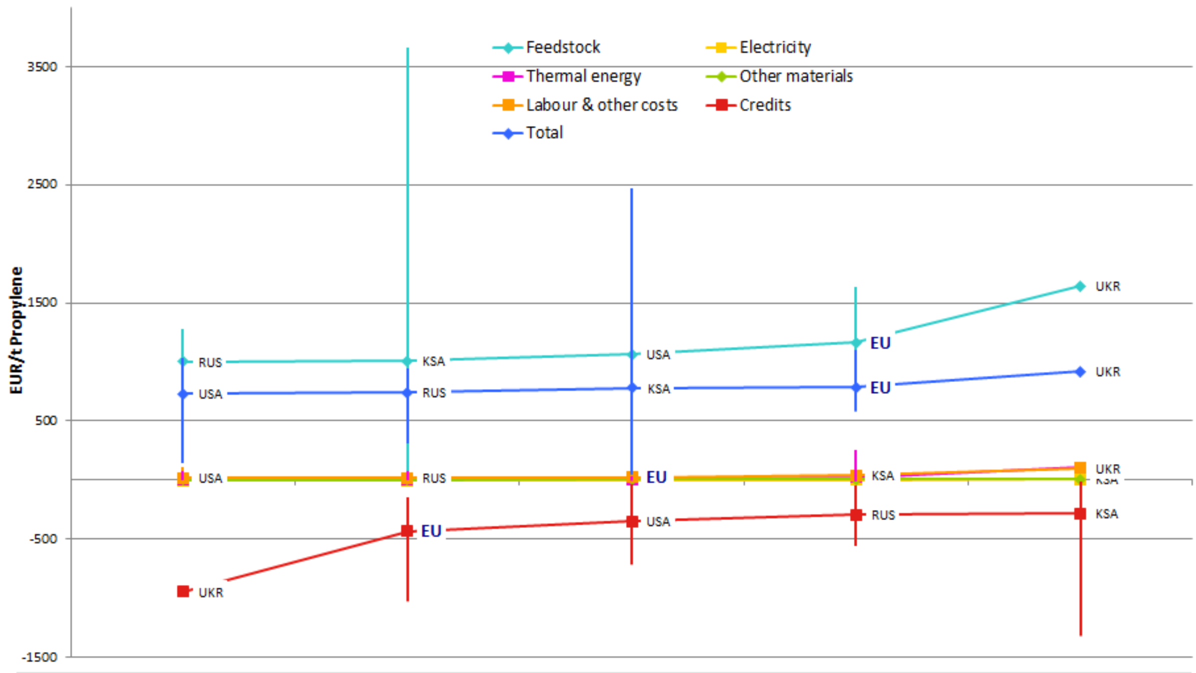

Figure 19: Average cost curves of propylene production in 2013 and intervals encompassing the maximum and minimum estimated costs

Propylene is sold in three different quality grades: refinery (55-75 %), chemical (92-96 %) and polymer (>99.5 %). Refinery grade (RF) propylene results from the refinery catalytic cracking (FCC) process, while propylene obtained from steam cracking and 'on-purpose' processes is at least chemical-grade (CG) purity up to polymer grade (PG). Thus, the analysis is done also for the two distinguished categories of grades separately.

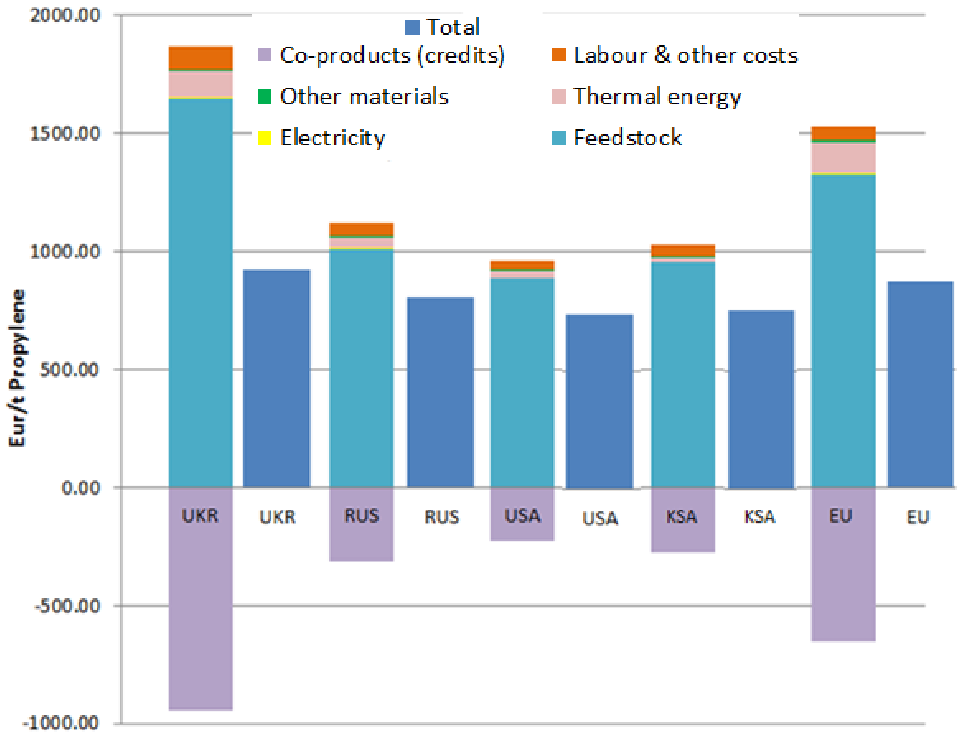

Figure 20: Summary of total industry costs per tonne of propylene polymer or chemical grade in 2013

Figure 20 and Figure 21 show the total costs in the case of chemical/polymer grade and refinery grade propylene respectively. The average cost curves are only produced for chemical/polymer grade product (Figure 22), as refinery grade propylene occurs only via FCC and there are no remarkable differences among the countries, as seen in Figure 21.

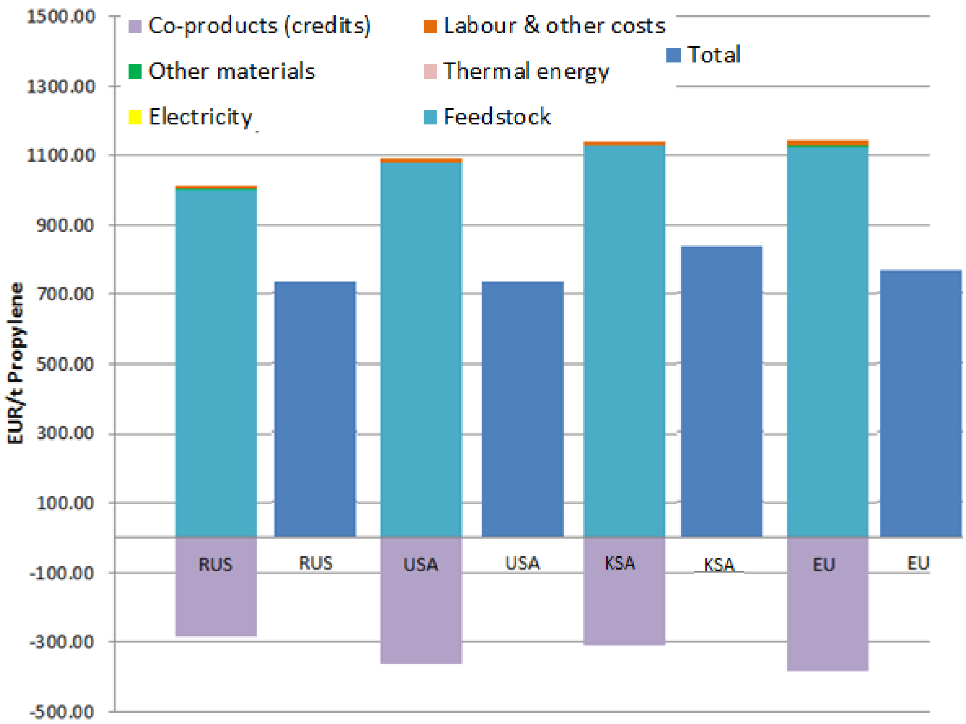

Figure 21: Summary of total industry costs per tonne of propylene refinery grade in 2013

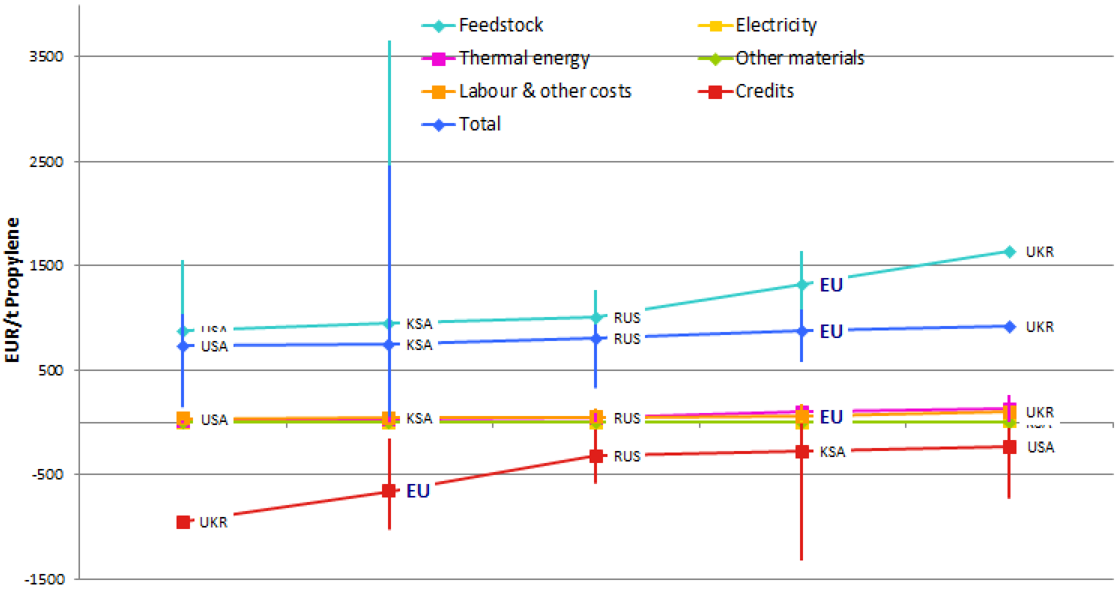

Figure 22: Average cost curves of propylene polymer or chemical grade production in 2013 and intervals encompassing the maximum and minimum estimated costs

3.4 Results for the non-ferrous industry

3.4.1 Results for the aluminium industry

In June 2015 the aluminium price (1 627 EUR/t) was quite close to the average value (1 620 EUR/t) of the last 10 years (from 2005 to 2014) [Indexmundi, 2015]. However, during 2012 and 2013 the average aluminium prices were 1 572 EUR/t and 1 391 EUR/t, respectively and the average of the estimated production costs of the EU industry for those years 1 411 EUR/t and 1 295 EUR/t, respectively (Figure 23).

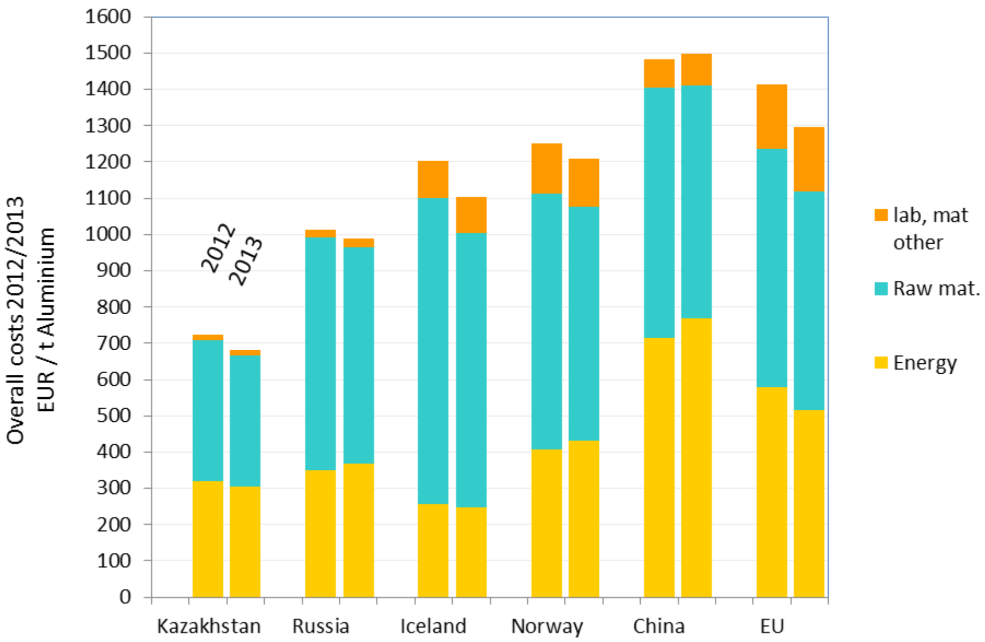

Figure 23: Summary of total production costs per tonne of cast aluminium in 2012 and 2013

Regarding the low aluminium production costs in Kazakhstan, it can be said that this country (with only one smelter of 0.24 Mt Al, in operation since 2010) has, together with Iceland among the lowest electricity prices; this fact, together with its low alumina price (from its own refinery) and low labour costs, results in the lowest production costs. In 2011, this smelter/country exported 40 % of its production to Russia, and the remaining 60 % was bought by the Swiss-based commodities trader Glencore [Pawlek, 2014].

On the other extreme there are the Chinese smelters. Out of the studied countries, it is the case in which high energy costs contribute the most to total aluminium production costs. Moreover, although the average cost under the 'labour and others' heading is much lower than the values in the EU, it shows a huge variability (Figure 24). That variability places the worst Chinese producers far from the rest of competitors. This can explain the observation that although Chinese aluminium production accounts for almost half of global production (46.6 %) they hardly export to the EU. In fact, Chinese smelters populate the fourth and third quartile of the cost curve [Djukanovic, 2012], despite the fact that they have some of the most energy-efficient smelters, and the number of smelters in construction is larger than the number of EU smelters.

The decrease of the production costs in the EU from 2012 to 2013 is mainly due to the decrease of electricity and alumina prices. In those 2 years, the wholesale market electricity price and alumina price fell around 13 % and 8 %, respectively. In the EU in 2013, only the electricity and alumina prices accounted each for around 40 % of total aluminium production costs.

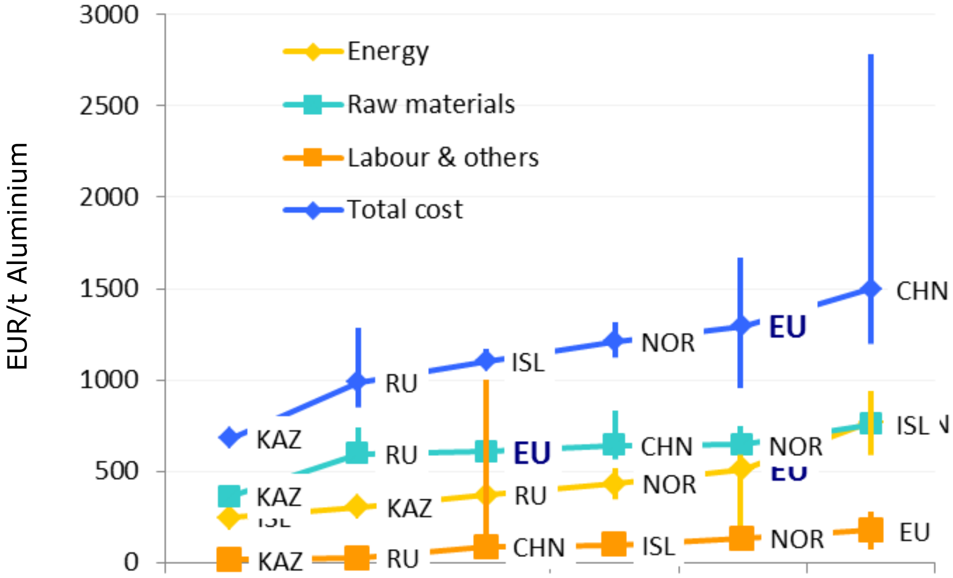

Figure 24: Average aluminium cost curve in 2013, and intervals encompassing the maximum and minimum estimated production costs

3.4.2 Results for the copper industry

As explained in Section 2, for copper the analysis distinguishes between copper smelters and copper refineries. Smelters receive copper concentrates from the mines and produce copper anodes, via the pyrometallurgical route, while refineries process copper anodes to produce copper cathodes. Figure 25 and Figure 27 refer to smelters and Figure 26 and Figure 28 to refineries.

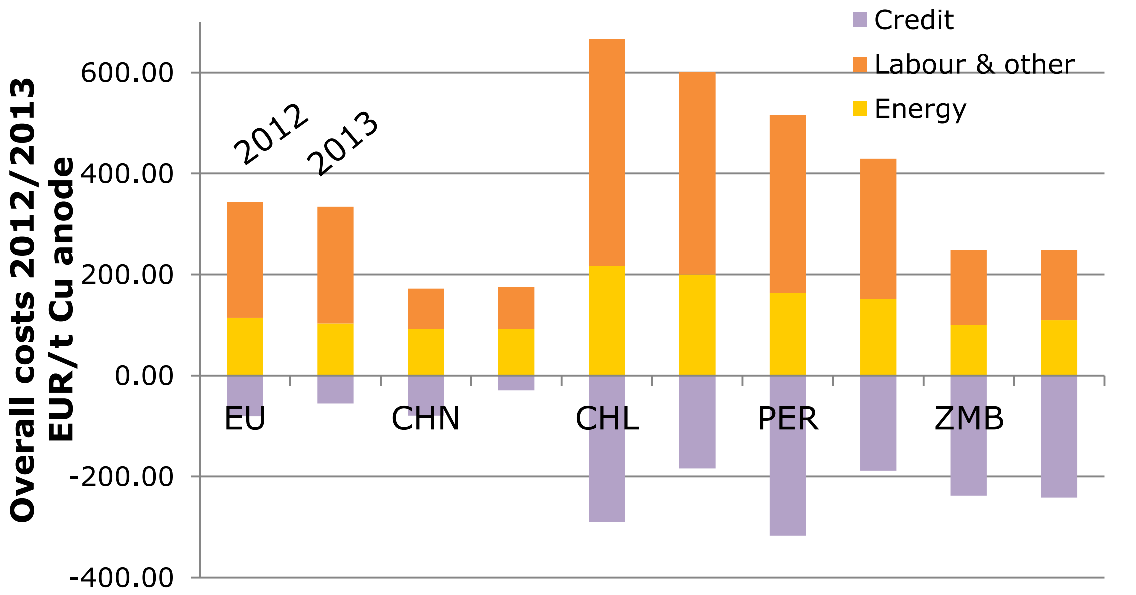

Figure 25: Summary of total production costs of copper smelters in 2012 and 2013

Figure 25 and Figure 26 summarise total copper production costs, excluding raw materials. The exclusion is due to the structure of the non-ferrous metals industry, where the raw materials price is decided in the international markets, and therefore, it is not considered a factor affecting the differences in production costs at national level. Energy costs are in most countries about 30-35 % and labour costs about 65-70 % of the total costs, both in copper smelters and copper refineries. The only exception is China where labour costs are still much lower than in the rest of the countries. Chile is the main copper producer in the world and copper is a major part of the country's income. Nevertheless, South America has higher production costs than other parts of the world. Chile had one of the highest electricity prices in 2013, explained by the shortage of electrical power in this country as a result of increasing consumption and lack of investments in the power generation infrastructure. Chilean smelters and refineries also have high labour remuneration rates.

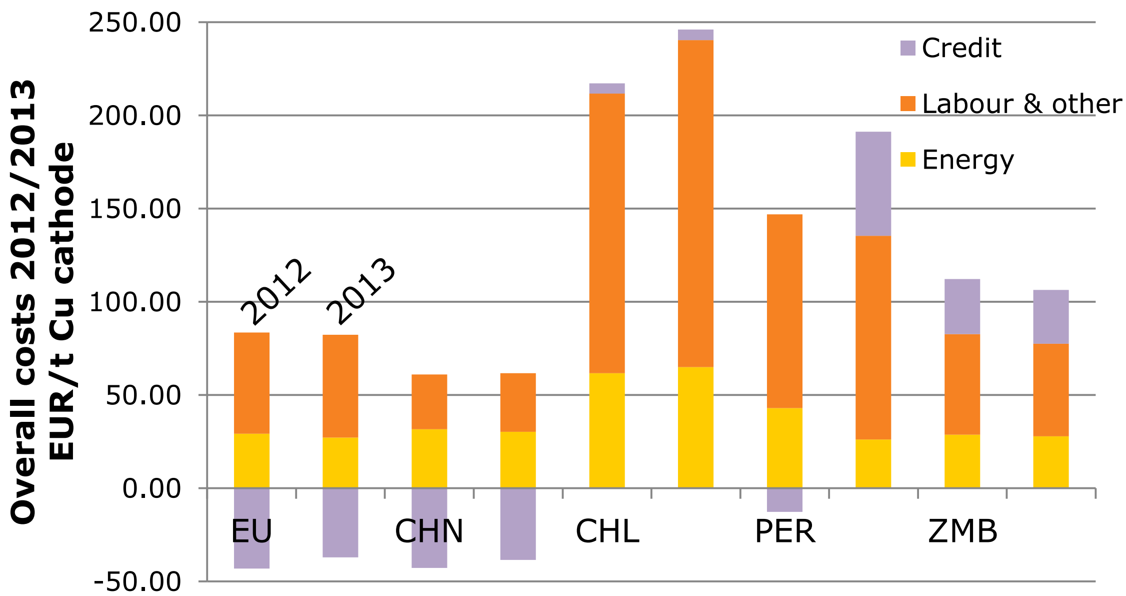

Figure 26: Summary of total refined copper costs in 2012 and 2013

On the other hand, though, smelters in Chile and Peru also have high credits, obtained from sulphur by-products. These smelters typically have arrangements to sell sulphuric acid on an intra-company transfer basis for metallurgical operations. They are, thus, less affected by the decreasing trends of sulphur prices globally.

In the case of copper refineries credits originate from nickel salts and cathode premiums. Nickel sulphate does not always offer the opportunity of a financial return, as it is an impure by-product that cannot be avoided. Cathode premiums are part of the revenue of copper refineries. They used to reflect the quality of the cathodes, but now they tend to reflect the projected supply and demand situation and freight costs to customers. In some cases they are not enough to cover these costs and therefore they seem to be penalties to copper refineries which are distant from their markets. They are included in the analysis, since disregarding them would distort the net costs of the copper industry.

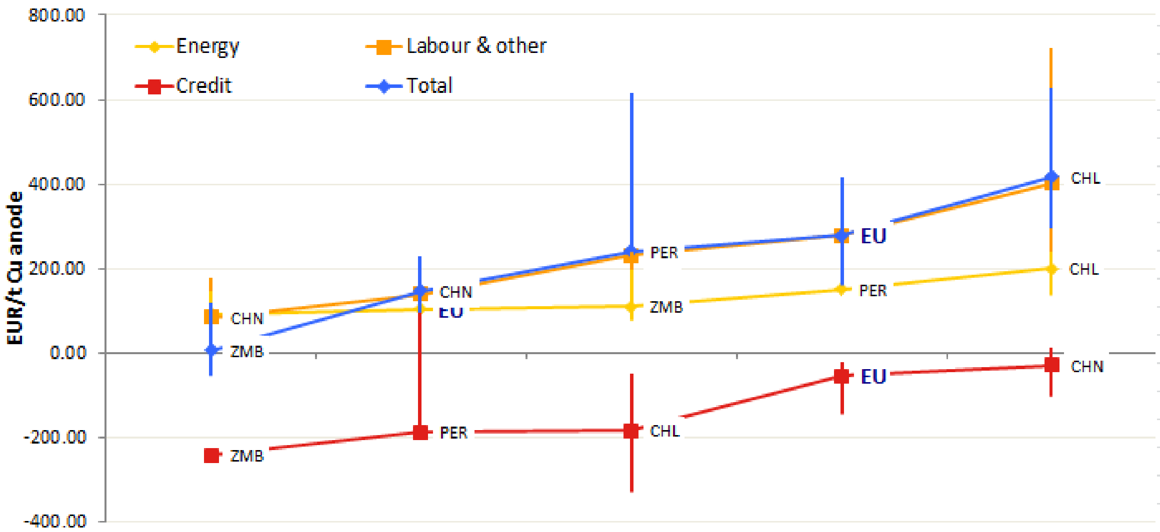

Figure 27: Average copper anode cost curve in 2013 and intervals encompassing the maximum and minimum estimated production costs

Figure 27 and Figure 28 show the average cost curves for copper smelters and refineries respectively. Especially for the copper refineries, the EU copper industry has much lower production costs than the countries from where most of the imports of copper cathodes originate. Due to high automation and high cathode premiums, the EU average is comparable to the average costs in China.

Concerning the price of copper in the LME, the average international prices of copper Grade A was 6 244 EUR/t in 2012 and 5 520 EUR/t in 2013 [Insee, 2015]. This price is directly passed from the final buyer to the mine after subtracting the treatment and refining charges that the smelters and copper refineries impose on the mines for their services. The average treatment and refining costs in the countries of interest in 2013 were 266-435 EUR/t of copper cathode, with the EU being in the lowest range and Zambia in the highest.

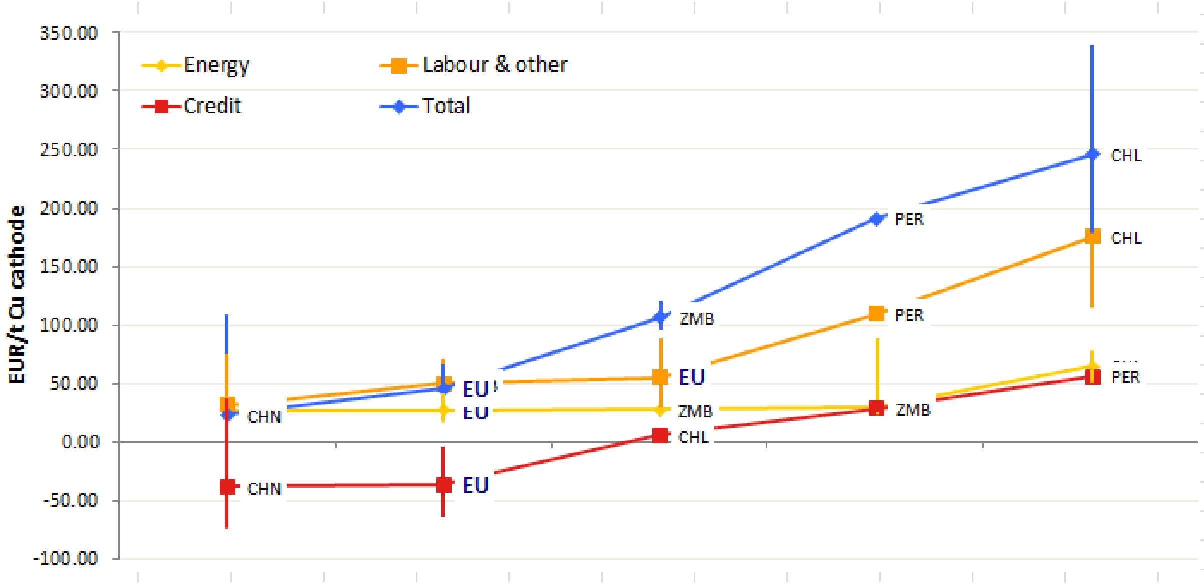

Figure 28: Average copper cathode cost curve in 2013 and intervals encompassing the maximum and minimum estimated production costs

3.4.3 Results for the zinc industry

The same analysis is done for zinc. The costs for the different components are summarised in Figure 29 and Figure 30 depicts the cost curves for 2013. In all countries the value of sulphur by-products and therefore credits are similar. Labour costs are the main component of costs in all countries, except China.

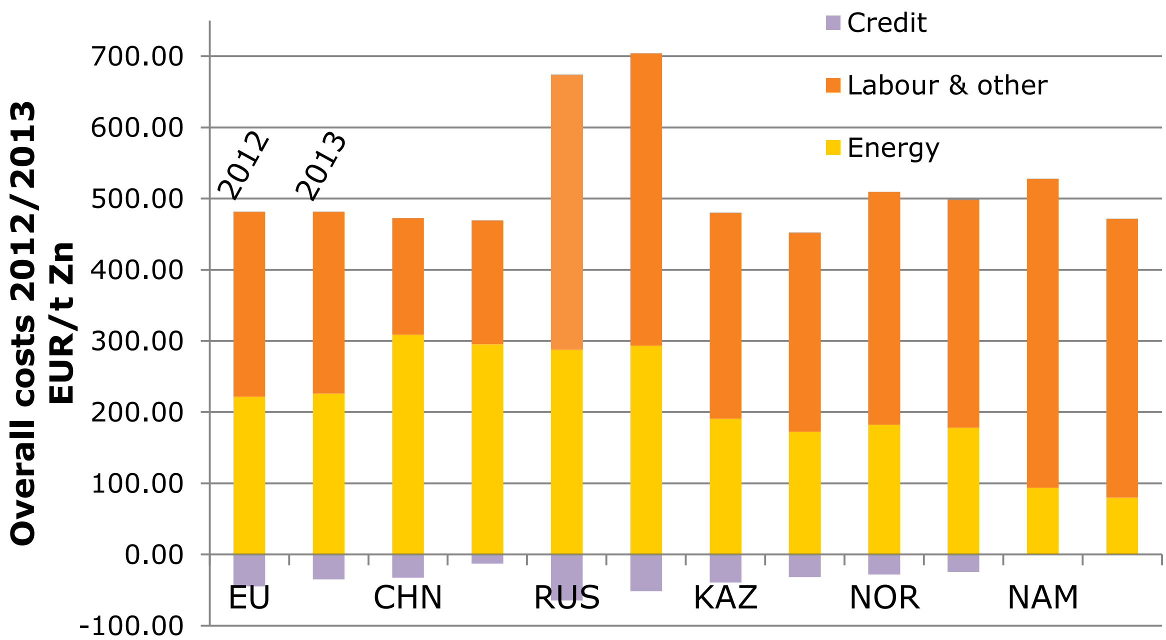

Figure 29: Summary of total zinc industry costs in 2012 and 2013

The average price for zinc settlement in 2012 and 2013 was 1 438.5 and 1 527.6 EUR/t respectively [Inees, 2015]. Raw materials are not part of the analysis, as their price is decided in the international market. The zinc price is paid directly to mines and should cover mining charges and treatment charges that zinc smelters ask from mines. Average treatment charges in 2013 were 259-373 EUR/t_{Zn} with Namibia, Norway and the UE in the lower range and China in the highest.

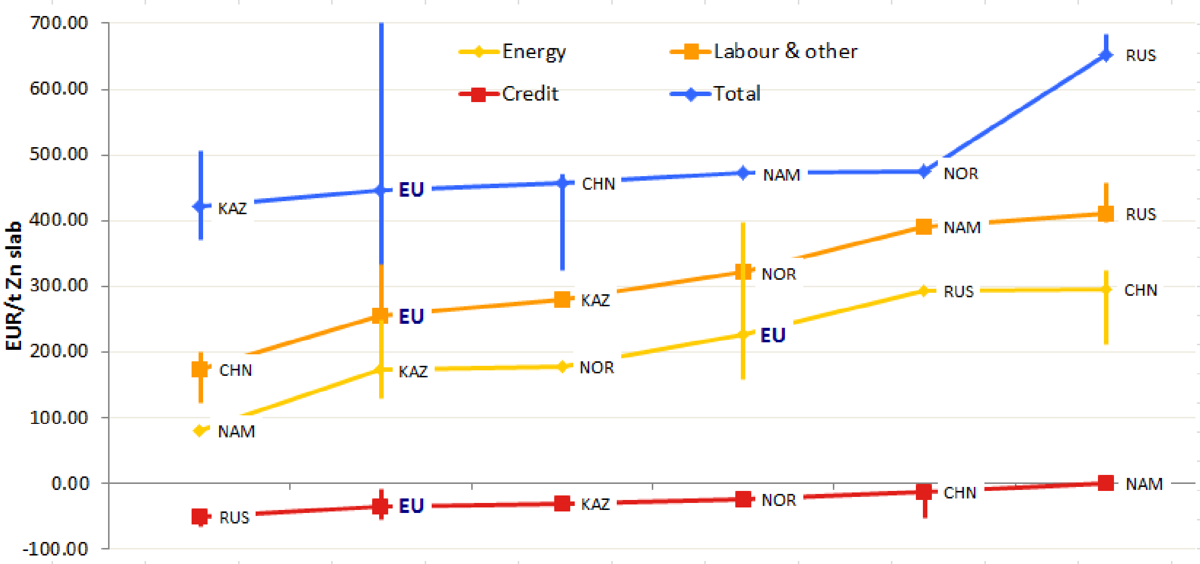

Figure 30: Average zinc cost curve in 2013 and intervals encompassing the maximum and minimum estimated production costs

4. Conclusions

The following conclusions can be drawn for the cement industry.

- The specific cost of thermal energy consumed by the EU cement industry is quite similar to that of the country with the lowest cost of thermal energy (China). However, when adding the electricity cost, the total EU energy costs per tonne of cement are the third highest of the five countries under study, but still well below those in Ukraine and Egypt.
- In three countries, Algeria, China and Ukraine, the observed cement prices are consistent with an estimation of these prices (the estimation is based on increasing the production costs a percentage in order to incorporate capital costs and profit). For the EU and Egypt, the estimation of prices is halfway between the estimated costs and the observed cement price.
- The difference between the average production costs in China and Algeria (36 EUR/t) and the EU average costs (48 EUR/t) is lower than the transportation cost of crossing the Mediterranean Sea (15 EUR/t).

The following conclusions can be drawn for the iron and steel industry.

- In almost all cases the country with the highest costs, Japan, is not far from the position of the EU, and Russia is revealed as one of the countries with the lowest costs.
- The variability in the energy costs does not affect the total costs as much as the variability in other components of the costs.
- The results from the top-down approach (data from the statistics) agree with the ones from the bottom-up approach (data at facility level). However, when looking at the energy costs (electricity and natural gas) using the bottom-up approach, one has to keep in mind that the industry, at least in the EU, makes good use of its waste gases. This fact is reflected in the term 'credit' that collects the savings for the industry of recycled scrap and self-power generation.
- For both products, flat and long, and almost for all countries, the total costs in 2013 for the EAF route are higher than for the BF-BOF route. This is mainly due to the raw materials costs (scrap) rather than the energy costs.

The following conclusions can be drawn for the chemical industry.

- Ammonia and methanol:
  - The decisive factor in the total costs is the feedstock. In the countries or regions where the feedstock (mainly natural gas) is locally produced (e.g. in the Middle East and in Russia), the production costs are much lower. The EU has the highest costs for both products.
  - The estimated average production costs for the EU ammonia industry in 2013 are about 14 % lower than the ammonia price in the western European market, considering that we have excluded the capital costs from the analysis.
  - The EU methanol industry seems to be facing strong competition.

- Ethylene and propylene:
  - Feedstock is an important component of the costs, but as steam cracking is a multi-product process, credits obtained thanks to co-products produced compensate for a part of the costs. The higher the price of fuels in a country, the higher the feedstock costs, but also the credits.
  - A major feature of steam cracking is the variety of feedstocks that can be used. Thus different parts of the world have adopted the feedstock most easily available. North America and Saudi Arabia production is based on domestic natural gas liquids (primarily ethane and propane), while in the EU and Russia ethylene producers favour petroleum liquid feeds. Ethane-based industries in general have lower production costs than naphtha-based industries, but the total costs are comparable in all countries of interest.
  - The price of ethylene in 2013 in the EU was about 1 125 EUR/t and the average total costs amounted to 748.4 EUR/t when considering ethylene as the main product or 816.2 EUR/t when both olefins are considered as products.
  - In the case of propylene almost all countries have comparable production costs, except Ukraine, where propylene is produced only with steam cracking. Higher production costs can be explained by the fact that steam cracking is not a process producing mainly propylene.

The following conclusions can be drawn for the non-ferrous metals industry.

- Aluminium:
  - The estimated average production costs for the EU aluminium industry in 2012 and 2013 are (10 % and 7 %) lower than the aluminium prices in those years. However, it should be noted that capital costs have been excluded from the analysis.
  - In the EU, the presence of some bilateral contracts means that the producers that benefit from them can have similar costs to Norwegian, Icelandic and some Russian competitors. (These low power prices also pull down the estimated average production costs.) Without these contracts, the best EU performer would have production costs similar to Iceland or Norway.
  - The extremely low aluminium production costs in Kazakhstan are explained by a combination of favourable factors such as low electricity prices (close to the second lowest costs in Russia), low cost of raw material (alumina comes from its own alumina refinery) and low labour costs.
  - The low electricity prices in Iceland, Norway and Russia, thanks to the hydroelectric origin of the power consumed, explain much of their cost advantage compared to the production costs in the EU, in which the energy costs account for around 40 % of total production costs.

- Copper:
  - The productivity of the EU copper industry is one of the highest in the world.
  - In the case of copper smelters, the EU has similar production costs to South American countries, which are the leaders in producing copper. China is still benefiting from low labour costs.
  - In the case of copper refineries, the EU has one of the lowest production costs. The higher recycling rate could be an advantage for the EU, as copper anodes can

be produced by either the primary or the secondary route and be processed in the same copper refineries.

- The EU copper industry has the lowest treatment and refining charges compared to the rest of the countries. With a rough estimation of the copper concentrates price, the sum of copper concentrates costs and treatment and refining charges in the EU was about 10 % lower than the copper price in the London Exchange Market in 2013.

- Zinc:
  - EU zinc smelters have some of the lowest total average production costs among the countries compared and one of the highest productivities.
  - European (EU and Norway) treatment charges are the second lowest, after Namibia. The sum of zinc concentrates (roughly estimated) and treatment costs in the EU was about 16 % lower than the zinc price in the London Exchange Market in 2013.

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ANNEX A. Production costs from the iron and steel industry in the EU and in third countries

A.1 Introduction

The purpose of this annex is to provide the results of a combined research and data collection exercise, using public and, where possible, commercial and industry data, aiming to establish different parameters that affect the cost and production process of the iron and steel industry.

The countries included in the collection of data are Brazil, China, India, Russia, South Korea, Turkey, Ukraine, the United States and the EU as a whole.

The second and third sections of this annex are devoted to describing manufacturing processes and provide a glimpse of the market status, whereas the fourth section details the research protocol followed in this report. The fifth section contains prices of energy and raw materials used, and the sixth section provides consumption of energy and raw materials. All this information is combined in the seventh section to produce an estimate of the production costs.

A.2 Iron and steel manufacturing

There are two main routes to produce steel. The first one is called the 'integrated route' and is based on production of iron from iron ore. The second one, called the 'recycling route', uses scrap iron as the main iron-bearing raw material in electric arc furnaces. In both cases energy consumption is related to fuel (mainly coal and coke) and electricity. The recycling route has a much lower energy consumption (about 80 %). In Figure 31 the 'integrated route' and the 'recycling route' are at the left-hand side and right-hand side of the continuous casting, respectively.

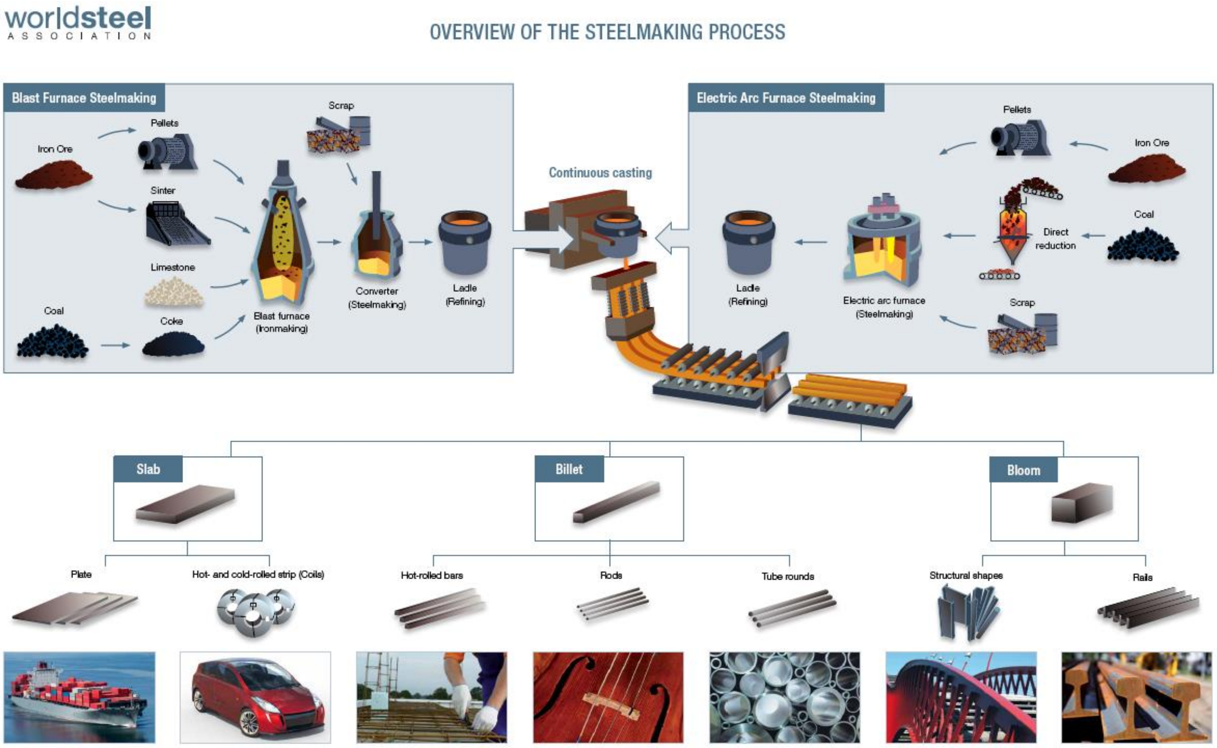


Figure 31: Overview of the steel-making process and variety of products manufactured [Worldsteel, 2011b]

The 'integrated route' relies on the use of coke ovens, sinter plants, blast furnaces and basic oxygen furnace (BOF) converters. Current energy consumption for the integrated route is estimated to lie between 17 and 23 GJ per tonne of hot-rolled product [SETIS, 2010]. The lower value is considered by the European sector as a good reference value for an integrated plant. A value of 21 GJ/t is considered as an average value throughout the EU-27 [SETIS, 2010]. It is noted that a fraction of this energy consumption may be committed to downstream processes. The fuels applied are fully exploited, first for their chemical reaction potential (during which they are converted into process gases) and then for their energy potentials, by capturing, cleaning and combusting these process gases within production processes, and for the generation of heat and electricity. Increased energy efficiency is an important characteristic of this 'cascadic fuel use', as the use of process gases does not reduce the overall energy consumption, which is the case if primary fuels are used for the chemical reactions.

The 'recycling route' converts scrap iron in electrical arc furnaces (EAF). Current energy consumption for this route is estimated to lie between 3.5 and 4.5 GJ per tonne of hot-rolled product [SETIS, 2010]. The lower value corresponds to a good reference plant. The higher value corresponds to today's average value within the EU-27.

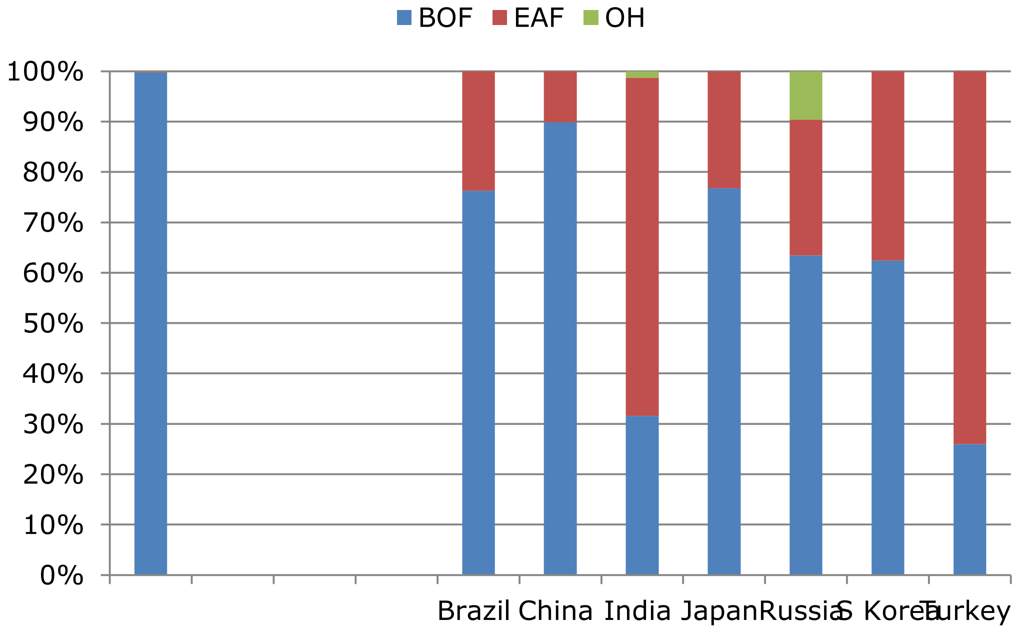


Figure 32: Crude steel production by process in the selected countries for 2012

There is an additional and older production process, practically replaced by the basic oxygen furnace, the open hearth furnaces (OH), where the impurities are removed from molten iron by blowing flames and heated air in alternating sequence. Almost all world production from this process is in Russia and Ukraine, where the production shares reached 9.6 % and 26 % respectively. In any case crude steel production using open hearth furnaces (16.4 Mt) represents a small share (1.1 %) of the global crude steel production.

Alternative product routes to the two main routes are provided by direct-reduced iron (DRI) technology (which produces substitutes for scrap) or the smelting reduction (which, like the blast furnace, produces hot metal). The advantage of these technologies compared to the integrated route is that they do not need raw material beneficiation, such as coke making and sintering, and that they can better adjust to low-grade raw materials. On the other hand, more primary fuels are needed, especially natural gas for direct-reduced iron technology and coal for smelting reduction. In the latter, 20-25 % savings in CO_2 emissions [Beer, 1998] can be achieved if the additional coal is transformed into process gases which are captured and used to produce heat and electricity for exports to the respective markets for heat and electricity. So far and for this reason, the expansion of these technologies occurs in developing countries with weak energy supply infrastructures or countries with low fuel resources. In 2012 total direct-reduced iron production was 70.9 Mt. The contribution of European DRI production boiled down to 0.65 Mt. In the third countries considered, only Russia and India have a production of DRI (5.2 and 19.7 Mt respectively). The accumulated DRI production of Egypt, Iran, Mexico, Oman, Qatar, Saudi Arabia, United Arab Emirates and Venezuela amounted to 36 Mt.

Part of the steep decrease in energy consumption in the EU industry in the last 40 years (by about 50 %) has been due to the increase of the recycling route at the expense of the integrated route (the share has increased from 20 % in the 1970s to around 40 % today). Although a prospective shift to recycling is confined by scrap availability and its quality, it is worth noticing (see Figure 32) that in three of the countries studied (India, Turkey and the United States), the share of the crude steel production from the EAF route is higher than from the BOF route (74, 67 and 59 % respectively) and higher than the share of the EAF route in the EU (42 %). This is the case also in the rest of the countries not included in the study (that represent around 9 % of the global crude steel production and where the overall production share of the EAF route amounts to up to 68 % of total production).

According to its final shape and use, steel can be classified in two big groups: flat and long products. The flat products, produced mainly by the integrated route, include labs, hot-rolled coil, cold-rolled coil, coated steel products, tinplate and heavy plate. They provide the highest added value to the steel and are used in automotive, heavy machinery, pipes and tubes, construction, packaging and appliances. The long products, produced mainly in the recycling route, include billets, blooms, rebars, wire rod, sections, rails, sheet piles and drawn wire. The long products are used in the construction, mechanical, engineering and automotive industries. However, the historically clear cut between the production route and long or flat products is waning out. Today 100 % of long products and 70-80 % of flat products can be made with scrap [Laplace Conseil, 2013].

A.3 Market and industry status

Production of crude steel in the EU in 2012 was 168.5 Mt, representing 10.9 % of total world production (1 547 Mt of crude steel) [Worldsteel Association, 2013]. Ten years earlier, with slightly higher production (188.2 Mt of crude steel), the share of the same EU countries was 20.8 %. The main difference is that Chinese production has grown fourfold over this period (from 181.9 Mt to 716.3 Mt of crude steel) [Worldsteel Association, 2013], see Figure 33.

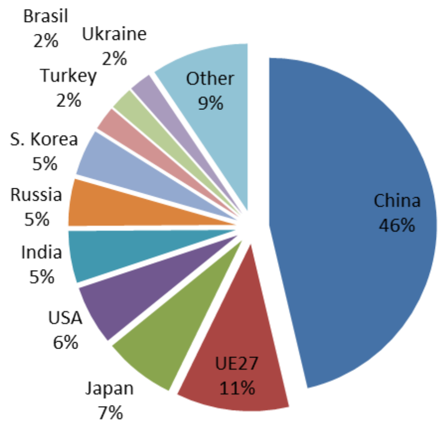


Figure 33: Percentage of crude steel production in 2012 [Worldsteel Association, 2013]

If we include Japan in the scope of the study, which we do from now, the production covered amounts to 91 % of global production in 2012.

In 2012 414.5 Mt of crude steel was traded internationally. The EU exported a total amount of 141 Mt and imported 133.3 Mt of crude steel, whereas 101.8 Mt were traded within the EU. This meant a net exporting balance for the EU of 8.8 Mt of crude steel. These figures should be seen in the context of production in the EU, which in 2012 amounted to 168.5 Mt of crude steel. The region that exported the highest amount to the EU was the CIS with 17.0 Mt of crude steel. At global scale the highest exchanges happened between China and other Asian countries (30.6 Mt), Japan and other Asian countries (26.8 Mt) and within other Asian countries (30.6 Mt). All values are from the Worldsteel Association [Worldsteel Association, 2013]. The world steel industry has an overcapacity of 542 Mt (out of a global expected capacity, by 2014, of 2 172 Mt) [EC, 2013]. Chinese overcapacity (200 Mt) is similar to the total production capacity in the EU of 217 Mt, and the overcapacity in the EU amounts to around 40 Mt [EC, 2013].

The ranking of the 20 top largest steel companies in the world (see Table 9) is populated by nine Chinese companies. Although the top world's largest producer in 2012 was a European company, the next European company is ranked 19th. It is noteworthy that the largest companies in Brazil, the EU and Japan represented 57, 56 and 45 % of the respective production in those countries. In India, Russia, South Korea and the United States those values varied from 23 to 30 %. In China the largest steel producer (ranked 3rd at global scale) represented only 6 % of Chinese production. In fact, the Chinese steel sector is scattered across approximately 1 200 companies; only about 70 of them have a production level greater than 5 Mt/year [CCAP, 2010].

Table 9: Top steel-producing companies in 2012 [Worldsteel, 2013]

Rank	Production in 2012 (Mt)	Company	Headquarters
1	93.6	ArcelorMittal	Luxembourg
2	47.9	Nippon Steel & Sumitomo Metal	Japan
3	42.8	Hebai Iron and steel	China
4	42.7	Baosteel Group	China
5	39.9	POSCO	South Korea
6	36.4	Wuhan Iron and steel	China
7	32.3	Jiangsu Shagang	China
8	31.4	Shougang	China
9	30.4	JFE	Japan
10	30.2	Ansteel	China
11	23.0	Shandong Iron and Steel Group	China
11	23.0	Tata Steel	India
13	21.4	United States Steel Corporation	United States
14	20.1	Nucor Corporation	United States
15	19.8	Gerdau	Brazil
16	17.3	Maanshan Iron and Steel Company	China
17	17.1	Bohai Iron and Steel Group	China
18	17.1	Hyundai Steel	South Korea
19	16.0	Gruppo Riva	Italy
20	15.9	Evraz	Russia

A.4 Research protocol

This document follows a two-fold approach to assess the different costs of the manufacturing processes: a bottom-up approach based on information from a data provider and a top-down approach using the international statistics available.

The facilities covered in this study about the iron and steel industry fall within the class 24.10 of the NACE Rev. 2 classification, that is, the manufacture of iron and steel and ferroalloys. This classification includes all the producers of the upper value chain even if they do not produce crude steel.

In the bottom-up approach, and in order to ease the comparability among plants producing the same products, this report uses the cost of the hot-rolled coil as representative of the costs from flat products, and the wire rod as representative of long products. The selection of these products is coherent with the approach followed in the assessment of cumulative cost impact for the steel industry [CEPS, 2013a].

However, unlike that report, and due to the world coverage of this study, this document also includes the analysis of the costs of hot-rolled coil from the secondary or 'recycling route' (EAF) and of wire rod from the 'integrated route' (BF-BOF). This is because, although flat products have been produced traditionally in the integrated route (BF-BOF), there are more and more facilities from the recycling route producing them. Also, there is still a significant number of integrated producers manufacturing long products. For example, in Ukraine, with a small share of steel production from the recycling route (around 5 %), the long products (from the integrated route) account for more than half of the Ukrainian steel production. The selection of hot-rolled coil and wire rod as representative products of flat and long products, besides keeping coherence with the approach of the Centre for European Policy Studies (CEPS), maximises the number of facilities covered by the study (see Table 10). Figure 34 shows a schematic evolution of the coverage of products by both routes.

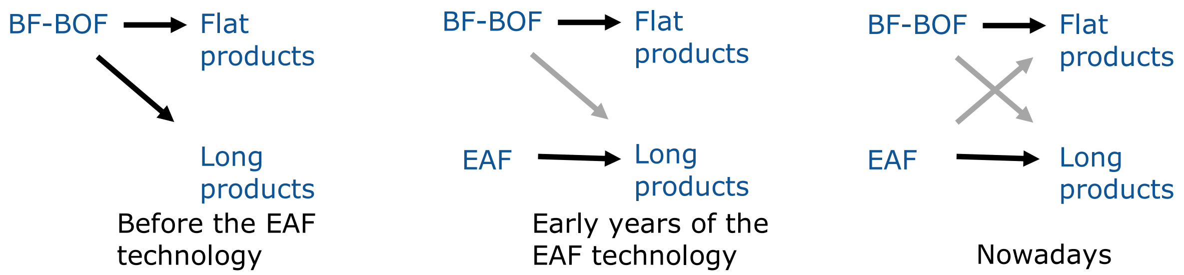


Figure 34: Evolution of long and flat products per production route

The sample of facilities used to analyse production costs is determined by the facilities covered by the data provider, World Steel Dynamics (WSD). Table 10 represents the number of facilities in the countries of interest, per technology and product.

Table 10: Number of facilities of WSD per technology and final product included in the bottom-up analysis

	BF-BOF Flat products (Hot-rolled coil)	EAF Flat products (Hot-rolled coil)	BF-BOF Long products (Wire rod)	EAF Long products (Wire rod)
Brazil	3	0	2	9
China	23	1	40	6
India	3	5	4	1
Japan	11	1	5	6
Russia	4	0	2	3
South Korea	3	2	1	1
Turkey	1	1	1	5
Ukraine	2	0	2	0
United States	14	7	0	7
EU	20	4	25	30
Total	84	21	82	68

On the other hand, the top-down approach starts from the detailed information about energy consumption per industry from the INDSTAT database [UN, 2014]. Although this alternative approach can come in handy to analyse the energy consumption per country and kind of fuel, it makes no distinction among technologies and products.

A.5 Components of the cost

In order to avoid any distortion of the cost of capital in different regions of the world (interest and depreciation of the equipment), that component is excluded from the cost comparison that follows in Section A.7.

In order to keep coherence with CEPS's reports [CEPS, 2013a; CEPS, 2013b], this study maintains the cost breakdown provided by WSD. As a result, the cost of the reductants (coal and coke) is included jointly with the iron ore and scrap in the epigraph of raw materials. It is worth noting that WSD includes only the cost of electricity and natural gas consumption in the energy costs reported. Energy and scrap credits correspond to savings in the scrap and energy required due to self-generation and use of own scrap. Also, the cost of the fluxes and other materials are included in the term 'other costs'.

5.1 Prices of energy, reductants and raw materials

Recently, a good deal of information gathered by some associations has been released in the form of some documents prepared by CEPS [CEPS, 2013a; CEPS, 2013b; CEPS, 2014] and incorporated by the European Commission [EC, 2014b]. Regarding prices, the main focus of those studies is on the electricity and natural gas prices because oil and coal are global commodities whose price differences are due only to transport. The Commission has recently prepared some staff working documents analysing the competitiveness of the industry [EC, 2014a; EC, 2014a] that take stock of this information.

Table 11: Natural gas prices in the EU (for different bands of consumption) for 2010, 2011 and 2012

	Natural gas price EUR/MWh		
	2010	**2011**	**2012**
(1) EU average of a sample of facilities	24.4	27.8	32.3
(1) EU median	**24.6**	**28.2**	**32.7**
(1) EU minimum	17.8	23.0	26.6
(1) EU maximum	35.4	47.9	59.1
(1) EU IQR (interquartile range)	6.8	7.3	13.0
(2) EU — Eurostat Band I6 (3) (> 4 000 000 GJ)	23.5	27.1	30.0
(2) EU — Eurostat Band I5 (1 000 000-4 000 000 GJ	25.6	28.2	31.9
(2) EU — Eurostat Band I4 (100 000-1 000 000 GJ)	28.1	31.1	34.5
(2) EU — Eurostat Band I3 (10 000-100 000 GJ)	32.5	36.5	40.1

(1) [CEPS, 2013b].
(2) [Eurostat, 2014].

Table 11 and Table 12 include the descriptive statistics of the prices of natural gas and electricity reported by CEPS. Those values are based on a survey carried out by Eurofer and show the variability of prices reported by the industry. Those tables also include the values reported by the different bands (based on consumption) of the industrial consumers. It is noteworthy that the band formed by the largest consumers is based on information reported by only a small number of countries. The values in that band are reported to Eurostat on a voluntary basis, but are based on at least three values for each country. According to Eurostat, especially for band Ig, the prices may result from

(3) The information for band I6 is the average of the natural gas prices of five countries (Germany, Spain, Italy, Hungary and Romania).

negotiated contracts, varying from one supplier to another. It is also relevant to underline the fact that long-term contracts are not forbidden per-se by EU competition law. Only when they involve a dominant supplier might they be ruled out under Article 102 TFEU. CEPS provides an interesting discussion of the effects of these long-term contracts for the industry in one of their studies [CEPS, 2013a, pp. 161-164].

Table 12: Electricity prices in the EU (for different bands of consumption)

	Electricity price EUR/MWh		
	2010	2011	2012
(1) EU average of a sample of facilities	66.8	71.2	71.4
(1) EU median	**58.7**	**67.4**	**62.3**
(1) EU minimum	51.8	51.0	46.5
(1) EU maximum	89.6	93.5	104.4
(1) EU IQR (interquartile range)	21.5	16.3	16.6
(2) EU — Eurostat band Ig ([4]) (>150 000 MWh)	68.4	64.7	69.6
(2) EU — Eurostat band If (70 000 MWh-150 000 MWh)	74.9	78.0	83.0
(2) EU — Eurostat band Ie (20 000 MWh-70 000 MWh)	82.6	86.9	92.2
(2) EU — Eurostat band Id (2 000 MWh-20 000 MWh)	91.4	95.1	102.1
(2) EU — Eurostat band Ic (500 MWh-2 000 MWh)	103.1	107.5	112.7

(1) [CEPS, 2013b].
(2) [Eurostat, 2014].

The values reported by CEPS, based on voluntary responses to a survey among Eurofer members (large consumers), are quite close to Eurostat values. However, the difference in Eurostat prices for the different bands is quite noticeable. It is also worth mentioning that, usually, when providing just a single price for the industry, the only value reported corresponds to bands 'Ic' and 'I3', for electricity and natural gas respectively. The difference between the prices of those bands ('Ic' and 'I3') and the corresponding to large consumers ('Ig' and 'I6') emphasises the need to use the right and coherent values for prices when making global comparisons.

For non-EU countries there is not such a degree of disaggregation (by band of consumption, as in Eurostat), therefore, we rely on the values reported by WSD. Although in the WSD application the different costs vary per facility,

Table 13 shows the average values of the facilities of the integrated route (BF-BOF) producing hot-rolled metal. The values corresponding to limestone, ferroalloys and oxygen have been taken from the INDSTAT database [UN, 2014] and jointly with the prices of electricity, natural gas, coal and iron ore (from WSD) serve to estimate the total production costs using a top-down approach.

([4]) The information for band Ig is the average of the electricity prices of eight out of the 28 EU countries (Bulgaria, Greece, Spain, Italy, Hungary, Poland, Slovakia and United Kingdom). Those countries include two of the three countries with the highest share of steel production from the recycling route (Spain 15 % and Italy 25 %); the third of the largest EAF producers, Germany with a share of 20 %, is not included in the sample.

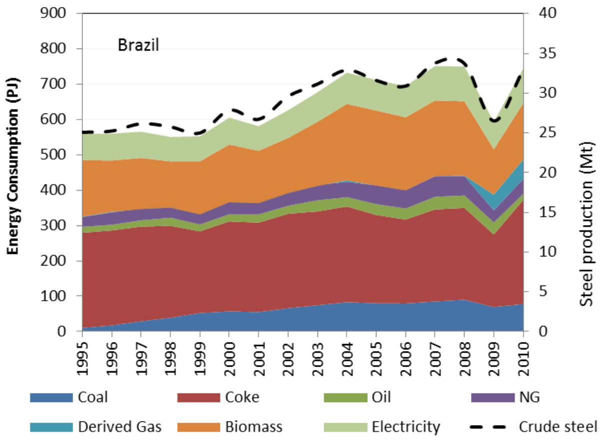
Table 13: Average prices of energy, reductants and raw materials from WSD (for producers of the BF-BOF route producing hot-rolled coil) and INDSTAT [UN, 2014]

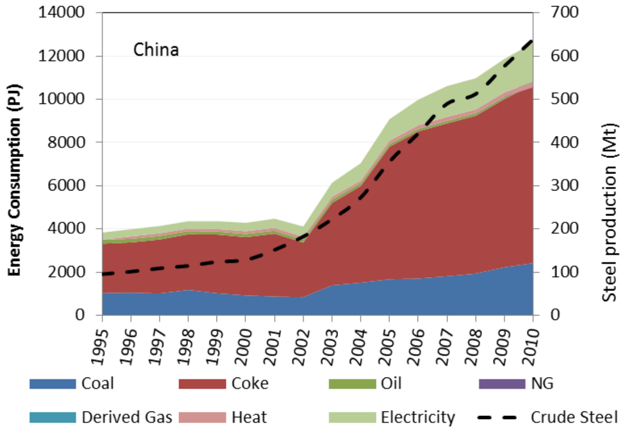
	Year	BRA	CHN	IND	JPN	RUS	KOR	TUR	UKR	US	EU
Electricity EUR/MWh	2011	52.0	59.1	63.4	48.3	24.5	50.5	55.7	33.4	50.8	53.8
	2012	54.1	63.2	63.0	51.0	30.6	52.6	58.8	47.1	53.6	61.2
	2013	48.2	66.7	58.7	39.9	41.4	52.0	54.2	68.5	51.5	84.1
NG EUR/MWh	2011	21.8	19.0	16.0	25.4	9.1	24.6	15.2	20.3	9.6	18.3
	2012	20.9	20.1	17.5	26.8	8.8	25.7	16.1	27.0	10.2	25.2
	2013	27.0	19.8	22.4	21.1	8.5	25.4	21.1	36.5	9.8	41.1
Coke EUR/t	2011	335.2	219.7	263.1	346.9	142.5	313.9	319.8	287.1	303.5	340.9
	2012	249.2	208.4	218.2	259.9	141.2	231.4	225.7	222.1	273.8	249.0
	2013	182.9	184.3	178.3	189.3	139.5	171.8	168.3	182.3	224.8	171.2
Coal EUR/t	2011	231.7	146.7	152.9	231.6	94.5	231.5	228.8	225.1	154.2	225.9
	2012	170.3	129.6	146.0	171.1	92.9	171.5	161.3	142.4	143.1	163.7
	2013	138.8	125.2	128.9	126.8	91.6	128.0	124.6	67.3	123.5	126.0
Iron ore EUR/t	2011	92.1	124.3	38.9	149.3	91.9	148.2	137.7	94.5	102.5	144.7
	2012	76.4	102.2	41.2	121.2	79.7	118.9	103.9	86.4	89.6	120.9
	2013	70.8	102.4	33.2	114.2	71.7	112.9	93.7	72.5	84.3	117.5
Scrap EUR/t	2011	252.3	344.0	348.5	340.1	273.4	356.0	344.0	275.8	335.3	329.9
	2012	231.5	309.5	335.5	292.2	261.8	325.2	335.9	237.5	305.9	304.6
	2013	184.3	262.8	291.5	276.7	231.9	288.7	291.2	225.7	279.1	266.3
Limestone EUR/t	2011	8.7	5.9	16.2	13.0	16.6	18.8	26.4	15.0	11.2	28.5
	2012	8.9	4.7	18.2	14.3	34.0	19.9	31.8	12.4	13.4	31.7
	2013	9.2		17.4	13.1		18.9	48.7	10.8	19.4	0.0
Ferro-alloy EUR/t	2011	1 766.7	1 295.1	1 689.4	1 437.2	965.5	1 464.2	1 266.1	1 689.4	2 124.3	1 594.7
	2012	1 940.5	1 521.8	1 804.6	1 357.1	983.1	1 537.7	1 189.5	1 777.8	1 433.5	1 515.9
	2013	1 791.0		1 787.0	1 217.0		1 283.0	991.0	1 449.0	1 916.0	
Oxygen EUR/kNm^3	2011	198.4	283.2				0.0	274.3	134.9		
	2012	228.1	350.4			191.2	0.0	310.0	132.1		
	2013						0.0	270.8	171.8		

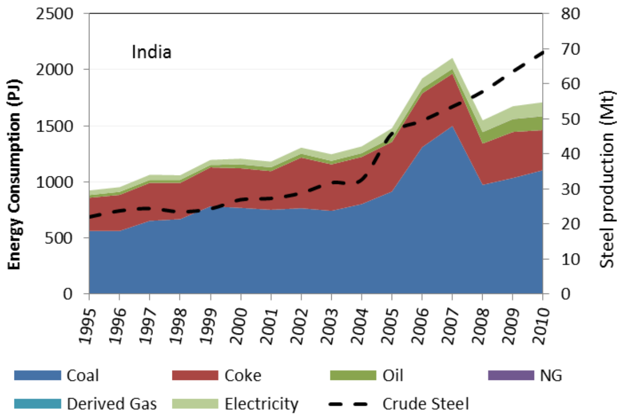
A.6 Energy consumption

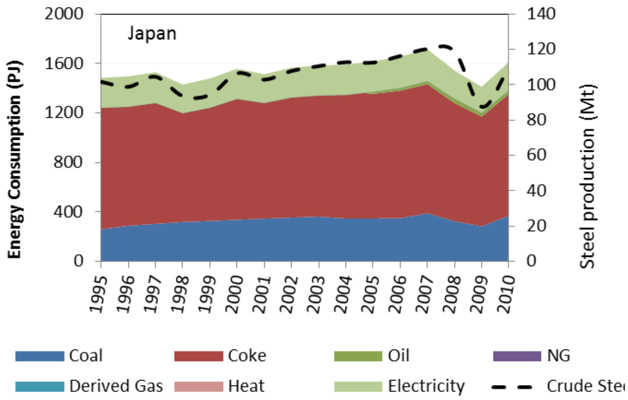
This section provides an overview of total energy consumption in the iron and steel industry per country and per fuel. This information is used in Section 7.5 to provide an estimation of the overall energy costs of the industry. Note that the estimation includes as energy consumption the coal and coke consumed as reductants. The information provided in Figure 35 is an extension of the values also reported in [Silveira et al., 2012] (from [UN, 2013]). It is also noteworthy that there is a time gap of three years in the most recent information at global level (from 2010 [UN, 2013]).

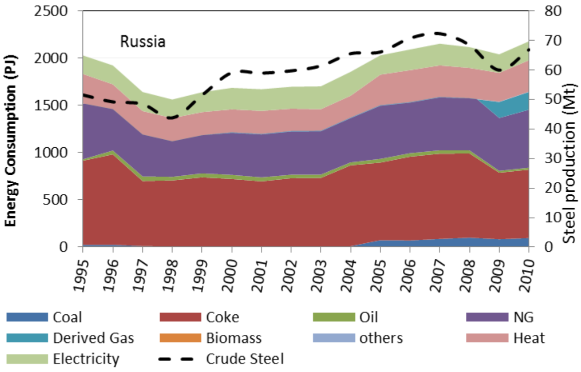
With the total crude steel production (Table 14) we can compare specific energy consumptions among regions. However, that value incorporates two very different specific energy consumptions: from integrate and recycling route. As a consequence **the final cost per tonne of steel is due more to the different presence of both routes in each country than to different performances of the technologies in the countries.**

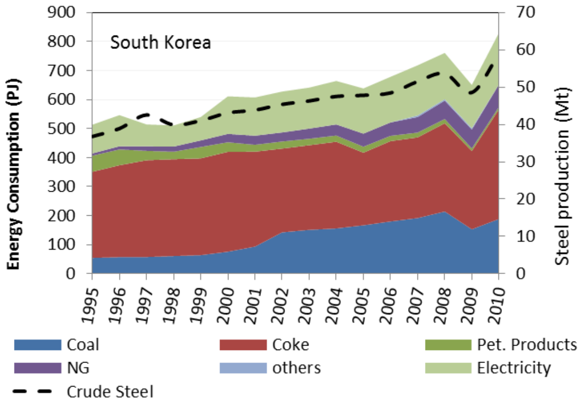

Brazil
Energy Consumption (PJ)
Steel production (Mt)
Coal
Coke
Oil
NG
Derived Gas
Biomass
Electricity
Crude steel

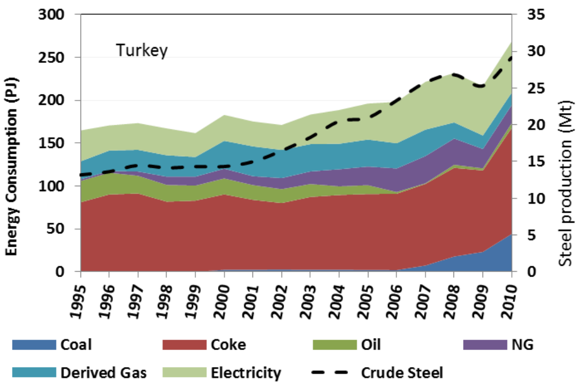

China
Energy Consumption (PJ)
Steel production (Mt)
Coal
Coke
Oil
NG
Derived Gas
Heat
Electricity
Crude Steel

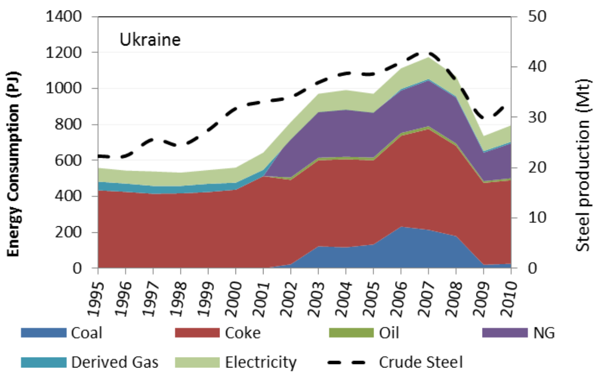

India
Energy Consumption (PJ)
Steel production (Mt)
Coal
Coke
Oil
NG
Derived Gas
Electricity
Crude Steel


Japan
Energy Consumption (PJ)
Steel production (Mt)
Coal
Coke
Oil
NG
Derived Gas
Heat
Electricity
Crude Ste


Russia
Energy Consumption (PJ)
Steel production (Mt)
Coal
Coke
Oil
NG
Derived Gas
Biomass
others
Heat
Electricity
Crude Steel


South Korea
Energy Consumption (PJ)
Steel production (Mt)
Coal
Coke
Pet. Products
NG
others
Electricity
Crude Steel


Turkey
Energy Consumption (PJ)
Steel production (Mt)
Coal
Coke
Oil
NG
Derived Gas
Electricity
Crude Steel


Ukraine
Energy Consumption (PJ)
Steel production (Mt)
Coal
Coke
Oil
NG
Derived Gas
Electricity
Crude Steel

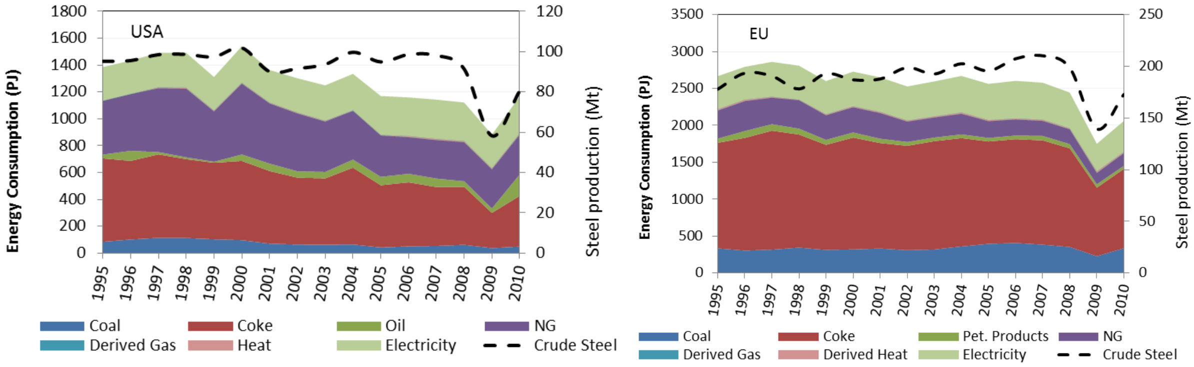


Figure 35: Total final energy consumption in the iron and steel industry in the countries under study (authors' update of [Silveira et al., 2012])

For the integrated route, the blast furnaces and basic oxygen furnaces (BF-BOF) of existing 'good reference' European plants are very close to the optimum, so there are very few possibilities of additional energy savings in this area. The best performers are at 17 GJ per tonne of hot-rolled product when the average is at around 21 GJ per tonne of hot-rolled product.

Table 14 presents final and specific energy consumptions of the overall industry (including both producing routes together) for the countries studied.

Table 14: Crude steel production, final energy consumption and specific energy consumption in the iron and steel industry

A.7 Costs

7.1 Energy costs

Combining the information of energy consumed (Table 14), the prices (Table 13) and the total production of crude steel (upper part of Table 14), we can produce Figure 36 with the specific energy consumption per tonne of crude steel. The estimations in 2011 and 2012 are derived by extrapolation of energy consumptions for those years and the prices reported in Table 13.

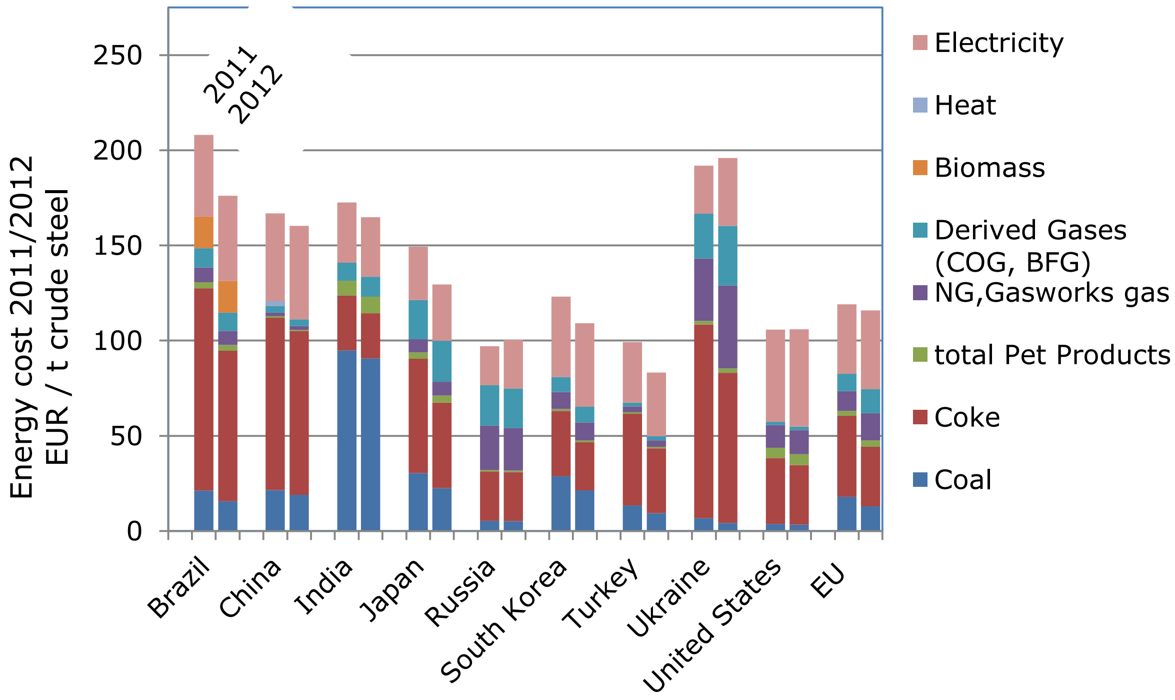


Figure 36: Energy and reductant costs in 2011/2012 (EUR/t crude steel)

For the price of the biomass, since the main country using biomass as fuel is Brazil, we have taken the charcoal price from Greenwood Management [GMA, 2014]. The price of the heat used is the same as the price of natural gas in the corresponding country, affected by an efficiency of 75 % [ETSAP, 2010] for the boiler.

As already mentioned, the costs shown in Figure 36 include the costs of the reductants (coal and coke), electricity, natural gas and other fuels, whereas in Section 7.5, where the costs are broken down by product and technology, the energy costs include only the electricity and natural gas costs.

7.2 Labour costs

For the top-down approach, the reference [UNIDO, 2014] provides information on employment, wages and other indicators by industry at 3-digit level of ISIC Revision 3. The information for the ISIC 2710 standard (basic iron and steel) is shown in Table 15. Combining this information with crude steel production in each country we can estimate the specific cost of steel due to the manpower used (Figure 37). However, these values have to be used with care because for some countries the information in [UNIDO, 2014] refers to 2008 (for South Korea and United States) and 2009 (for India and Turkey), and in any case, the remaining values referring to 2010 might not reflect recent changes in the labour market.

Table 15: Number of employees and wages per employee (at current prices) in the iron and steel industry in 2010 (*), 2008 (**) and 2009

Country	Number of employees	Wages (EUR/employee)
BRA	135 106	18 859
CHN	3 456 200	6 217
IND**	598 952	2 619
JPN	147 413	41 705
RUS	324 482	7 270
KOR*	76 688	29 803
TUR**	58 768	12 002
UKR	538 729	3 826
US*	188 471	45 085
EU	473 834	33 002

For the bottom-up approach, using WSD data, each facility has a particularised productivity (man-hours per tonne of product) that, together with the hourly wages, defines the labour costs per tonne of product reflected in Figure 38 to Figure 41.

7.3 Raw materials costs

In order to follow a top-down approach, besides the prices collected in Table 15, we need an estimation of consumptions or raw materials and fluxes per tonne of crude steel. In this case we will use the consumptions shown in Table 16 for all countries [Moya, 2013]. Needless to say, with WSD data (bottom-up approach), each facility has different specific consumptions.

Table 16: Raw materials consumption per tonne of crude steel

t/t crude steel	BF-BOF	EAF
t iron ore	1.397	
t scrap	0.161	1.09
t limestone	0.202	0.085
kNm3 oxygen	0.091	
t ferrosilicon	0.004	0.004

The values of Table 16 include all processes involved in crude steel production. For example, the 0.202 tonnes of limestone per tonne crude steel comes from consumption of 0.131 tonne of limestone per tonne of sinter and a consumption of 1.245 tonne of sinter per tonne of hot metal, assuming 0.937 tonnes of hot metal per tonne of crude steel. The 0.202 also includes an additional consumption of 0.049 tonnes of limestone per tonne of crude steel in the own BOF.

7.4 Overall costs

Figure 37 summarises all costs obtained following the top-down approach. In order to enable the comparison of these results with the ones obtained with WSD data (bottom-up approach), we use the same breakdown of costs. That is, under the energy costs there are only natural gas and electricity costs. The raw materials costs cover the use of iron ore, scrap and reductants, and finally 'other costs' include consumption of fluxes and other consumables.

If we exclude the labour and regulation costs of the comparison, **the costs in the EU (only including raw materials, energy and other costs), are higher than the Brazilian and Russian costs, lower than the Indian costs and in line with the rest of the competitors.**

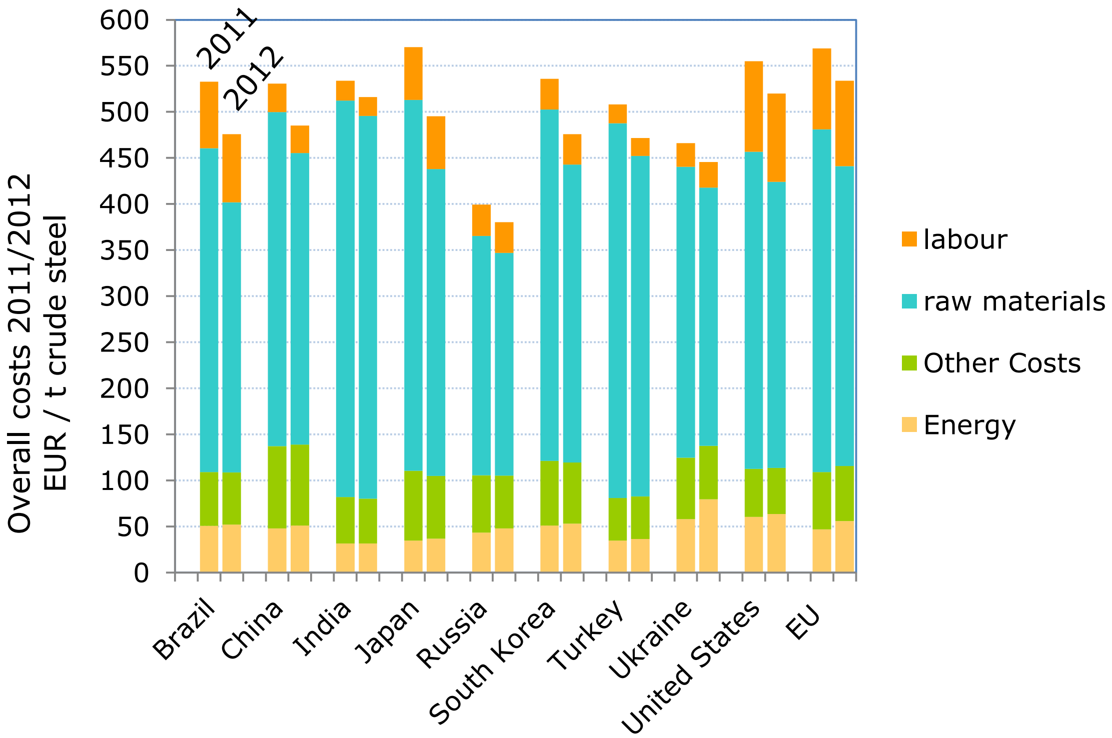


Figure 37: Summary of total iron and steel industry costs per tonne of crude steel (using the top-down approach) (5)

Following the bottom-up approach, which means basing the analysis on data at facility level, Figure 38 and Figure 39 represent the specific costs of each country, ranking the countries in the horizontal axis according to their increasing average total costs. Each vertical line in each country is the range between the minimum and maximum cost observed in any facility of the sample provided by WSD. The number of facilities in the sample can be seen in Table 10. The number of European facilities producing hot-rolled coil in the BF-BOF and EAF routes is 20 and 4, respectively. The fact that not all producers of the recycling route (EAF) are able to produce all flat products is reflected in the lower number of facilities that form part of the sample used to produce Figure 39 (21) compared with the number of facilities used to produce Figure 38 (84). Although the reports [CEPS, 2013a; CEPS, 2013b] did not include the cost of producers of the recycling route producing flat products, that information, shown in Figure 39, is included

(5) Although there is an estimation of the regulation costs for the EU, from the CEPS report, this concept is not included in this figure due to the lack of similar information for third countries.

in this analysis. As a general trend, it can be said that in 2013 the recycling route had higher costs of production than the integrated route producing hot-rolled coil (the curve of total cost in Figure 39 is always higher than in Figure 38).

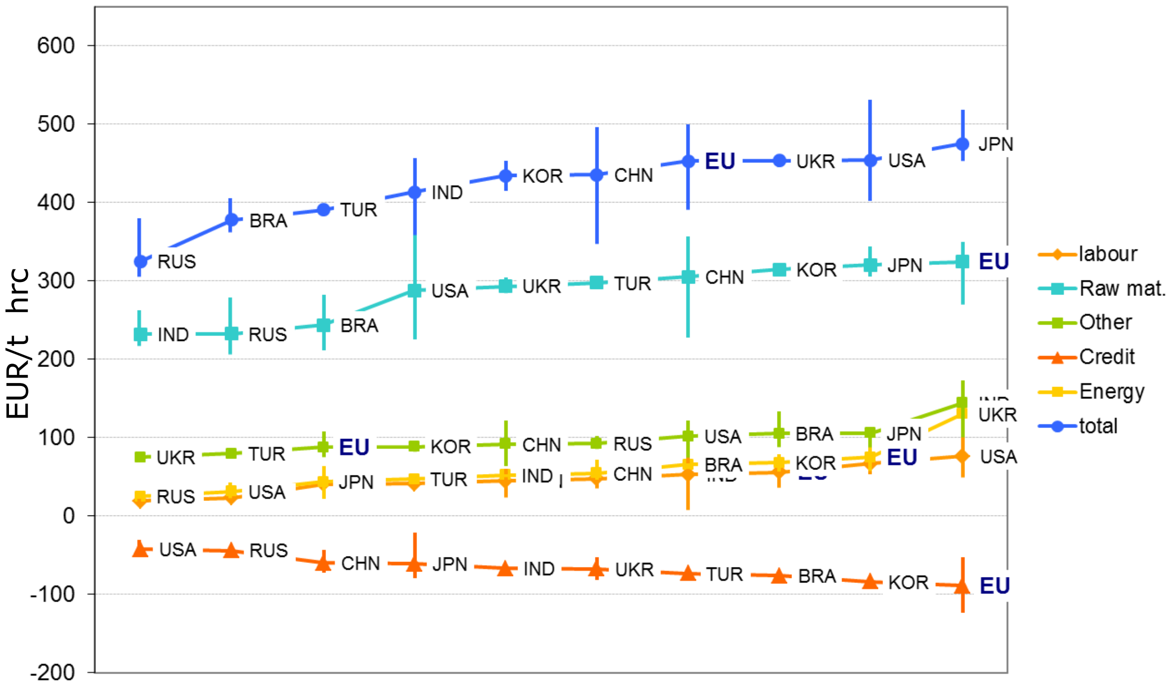


Figure 38: Mean cost curves in 2013 of hot-rolled coil in the integrated route (BF-BOF)

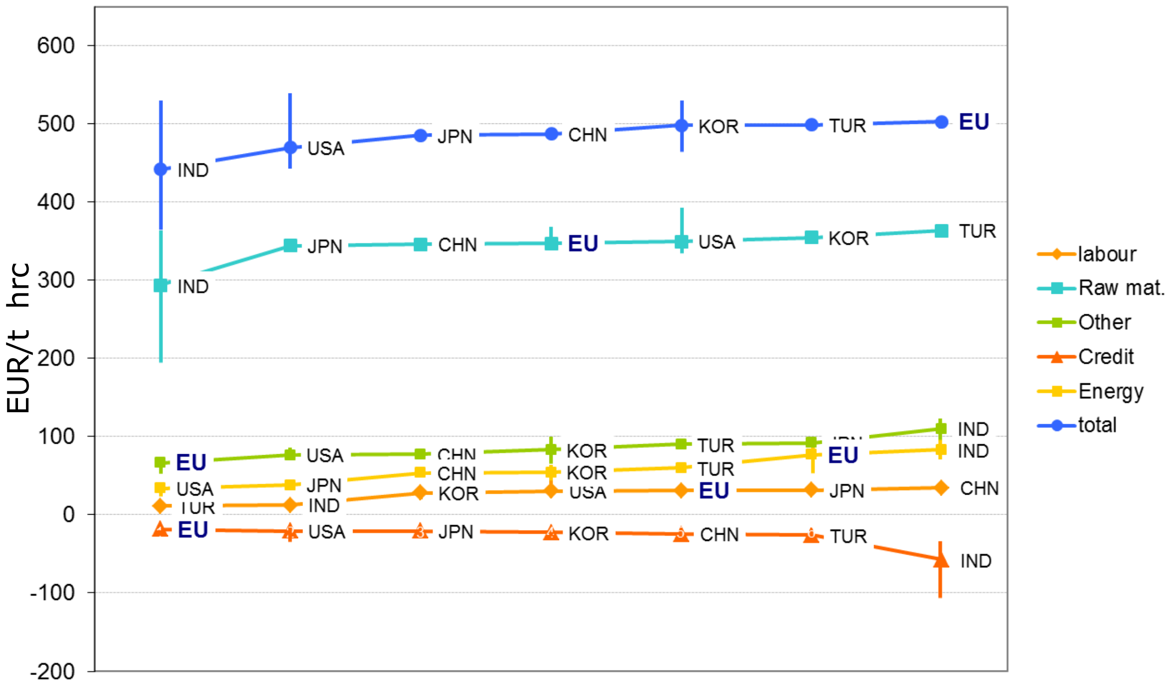


Figure 39: Mean cost curves in 2013 of hot-rolled coil in the recycling route (EAF)

In Figure 39 the variability of the country with the lowest average total cost (India) embraces the average cost of the region with highest costs (the EU). That is not the case in Figure 38, where there is no overlap in the intervals of the country with lowest total production costs (Russia) and the one with highest total production costs (in Figure 38, Japan). Moreover, also in Figure 38, the average cost of country with highest production costs (Japan) is around 50 % higher than one with lowest production costs (Russia), whereas the similar percentage for Figure 39 is 14 %.

Figure 40 and Figure 41 are similar to 38 and 39, but demonstrate the case for production of wire rod as representative product of long products. The CEPS reports did not include cost information on production of long products from the integrated route (information shown in Figure 40).

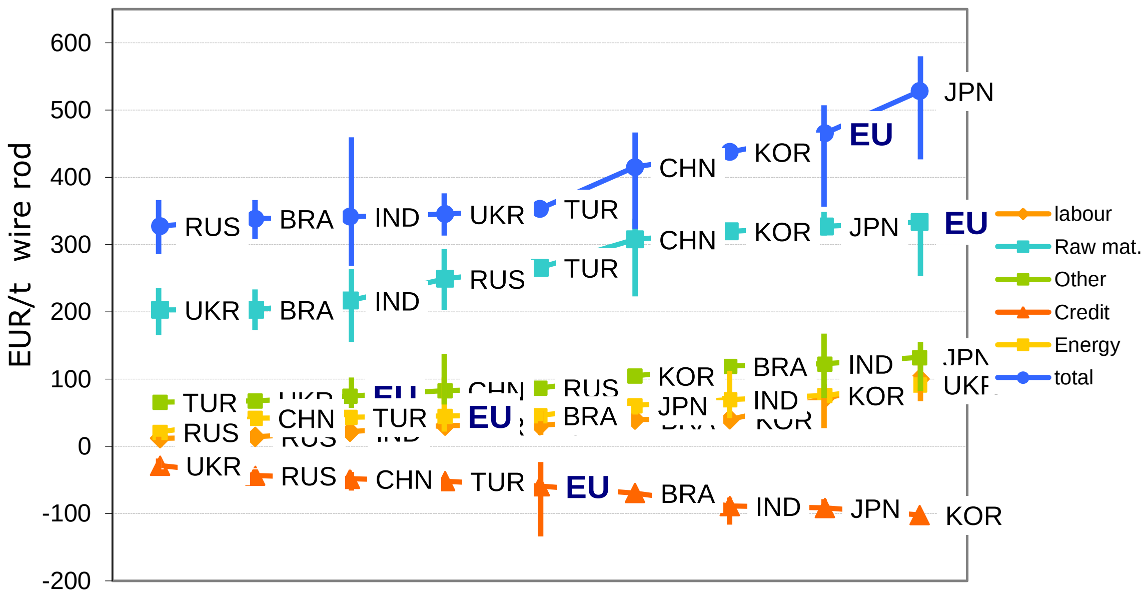


Figure 40: Mean cost curves in 2013 of wire rod in the integrated route (BF-BOF)

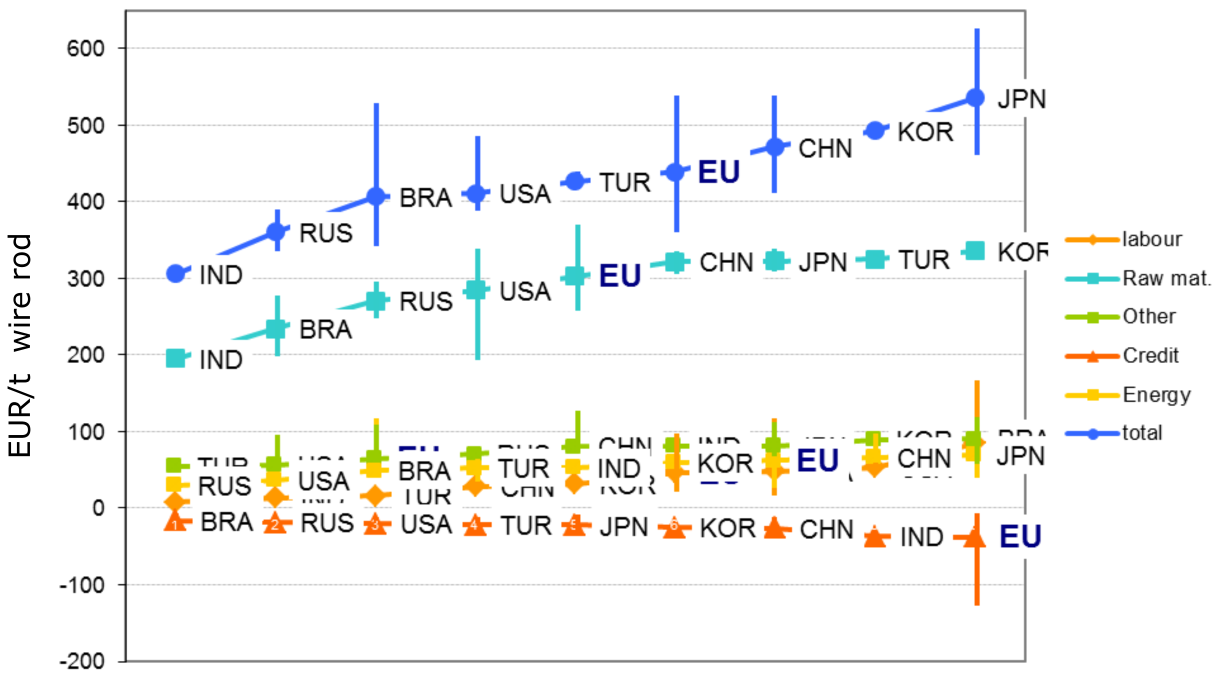
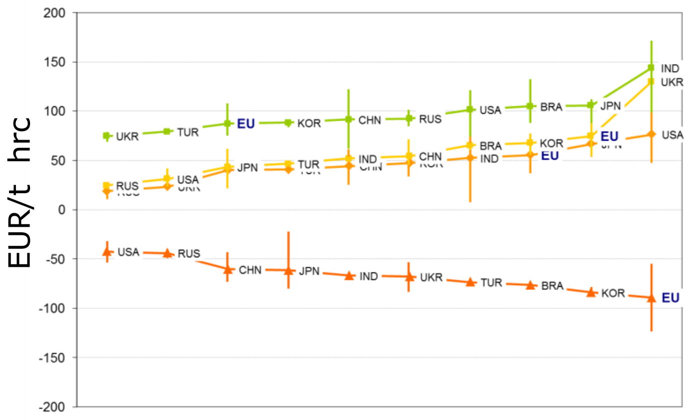


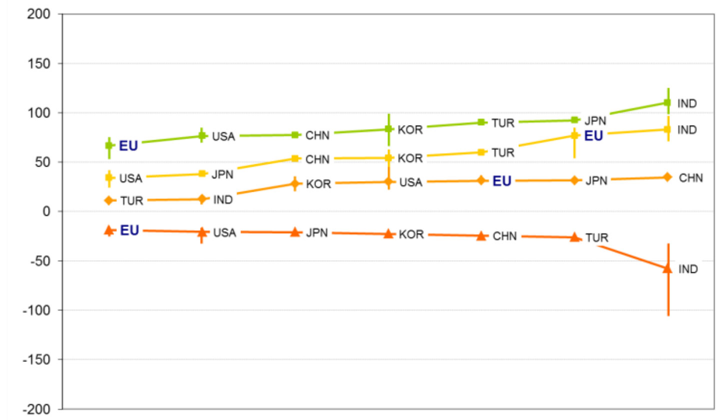
Figure 41: Mean cost curves in 2013 of wire rod in the recycling route (EAF)

For Figure 40 and Figure 41 the variation of percentage between the average cost of the countries with highest and lowest production costs is 61 and 75 %. There are also big overlaps among the ranges of costs in almost all countries.

Figure 42 contains the same information as Figures 38 to 41, but with a larger y-axis so as to be able to make out the relative position of the different countries for the lower curves of Figures 38 to 41.

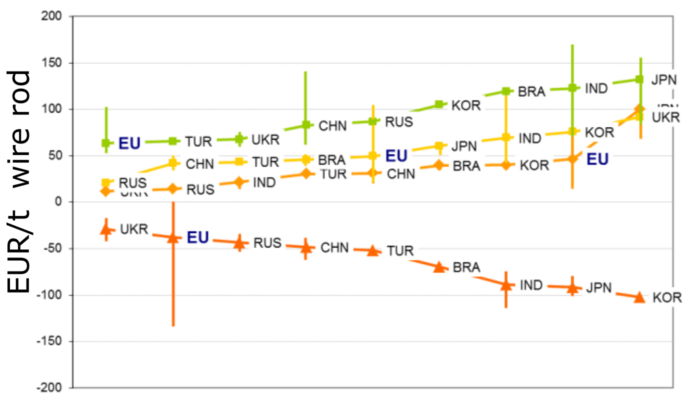


a) Mean cost of **hot-rolled coil** from **BF-BOF**

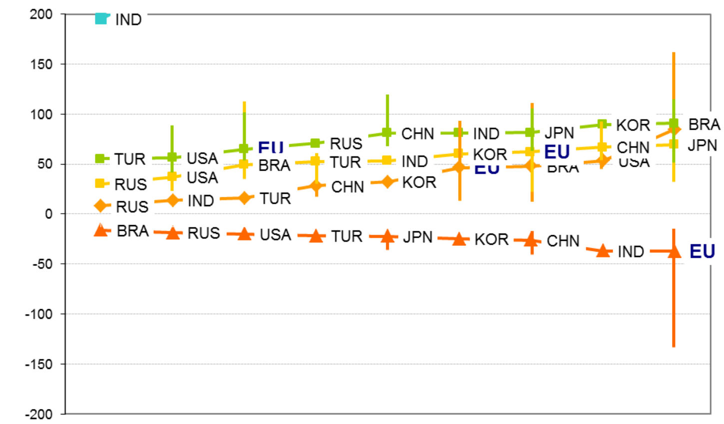


b) Mean cost of **hot-rolled coil** from **EAF**

labour Other Credit Energy



c) Mean cost of **wire rod** from **BF-BOF**

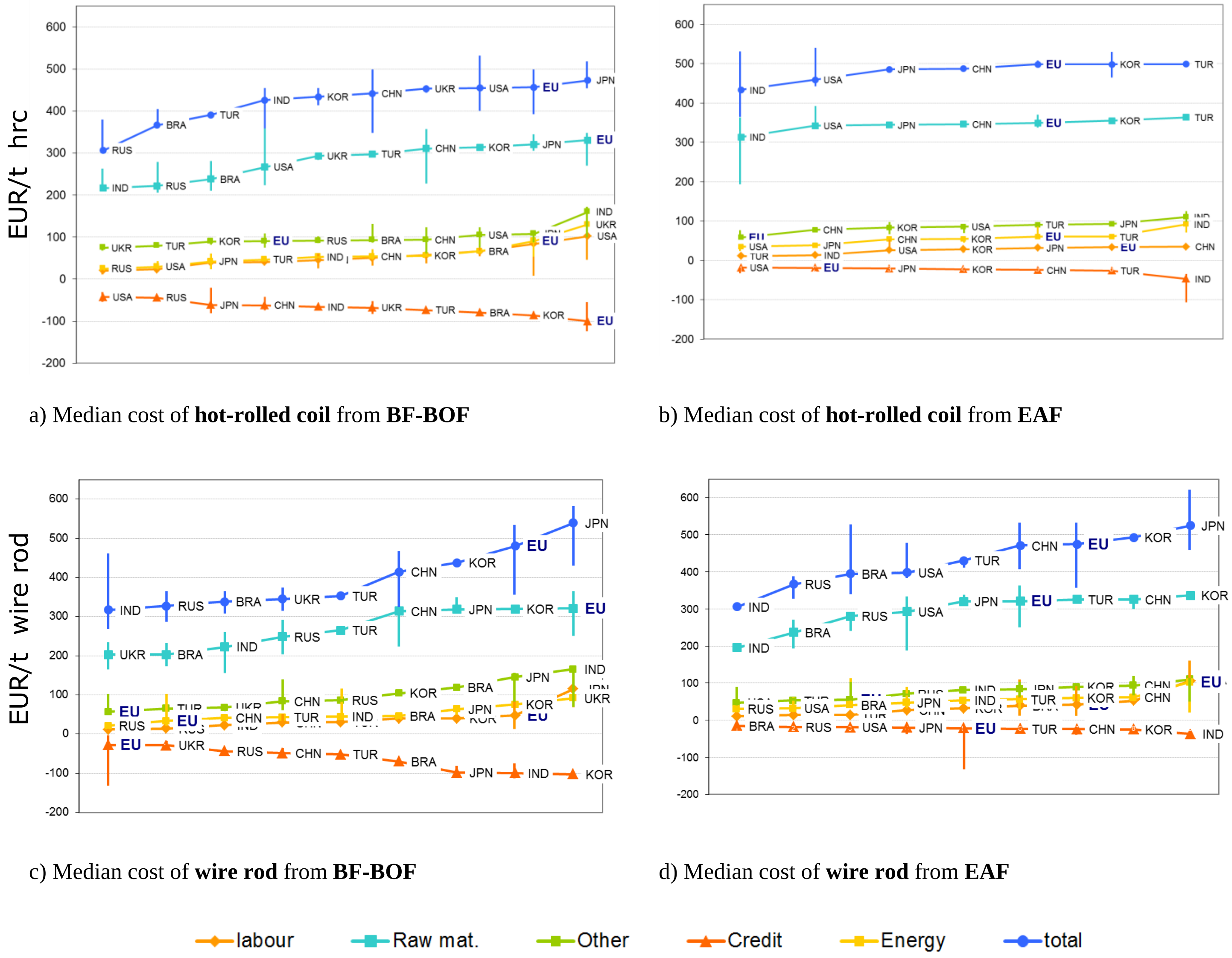


d) Mean cost of **wire rod** from **EAF**

labour Other Credit Energy

Figure 42: Details of the iron and steel cost curves for the low ranges of the costs

In Figure 38 to Figure 41 the position of each country corresponds to the average value of the respective costs. However, the mean is a non-robust measure of central location, meaning that one or more outliers (extreme high or low values in a sample) can pull (or drag) the value of the mean upwards (or downwards). A more robust measure of central location is the median, defined as the numerical value separating the higher half of the data sample from the lower half. Figure 43, from (a) to (d), shows the position of each country when using the median as sorting criterion. There are some variations in the position of some countries. For example, in Figure 38 the EU was the fourth highest production cost whereas in Figure 43(a) it is the second highest. In any case, the values of intervals drawn do not change (the maximum and minimum costs in each country are the same). The aim of this discussion is to show the sensitivity of the relative position of the countries when using one statistic or another (the mean in Figure 38 to Figure 42 and the median in Figure 43).



a) Median cost of **hot-rolled coil** from **BF-BOF**

b) Median cost of **hot-rolled coil** from **EAF**

c) Median cost of **wire rod** from **BF-BOF**

d) Median cost of **wire rod** from **EAF**

Figure 43: Cost curves for the iron and steel industry using the median of the cost as ranking criterion

Also as validation, the conclusions that can be drawn from information in Figure 37 (which summarises the result of production costs in the industry following a top-down approach) are in line with the information from Figure 38 to Figure 41 (obtained with the bottom-up approach). **In both cases the country with the highest production costs, Japan, is not far from the position of the EU, and Russia is revealed as one of the countries with lowest production costs.**

Note that the costs described are ex-factory prices, in other words, they do not include shipping, handling, taxes or customs. Also, the capital costs (interest and depreciation) are excluded from the comparison of production costs. It is also worth underlining that, in the bottom-up approach, the number of facilities included in the sample for some countries does not ensure a comprehensive representation of the industry and its variability in those countries, and therefore the results, although indicative, cannot be conclusive.

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ANNEX B. Production costs from the cement industry in the EU and in third countries

B.1 Introduction

The purpose of this annex is to provide the results of a combined research and data collection exercise, using public and, where possible, commercial and industry data, aiming to establish different parameters that affect the cost and production process of the cement industry.

The countries included in the collection of data for the cement industry are Algeria, China, Egypt, Ukraine and the EU as a whole.

The second and third sections of this annex are devoted to describing manufacturing processes and provide a glimpse of the market status, whereas the fourth section details the research protocol followed in this report. The fifth section contains prices of energy and raw materials used, and the sixth section provides consumption of energy and raw materials. All this information is combined in the seventh section to produce an estimate of the production costs.

B.2 Cement manufacturing

Most of CO_2 emissions and energy use in the cement industry are related to the production of clinker. Clinker, the main component of cement, is obtained through the calcination of limestone. 62 % of the CO_2 emissions emitted during the fabrication of cement come from the calcination process, while the rest (38 %) is produced during the combustion of fossil fuels to feed the calcination process [BREF, 2013].

Four processes are currently available to produce clinker: wet, semi-wet, semi-dry and dry. All these processes share the same main steps in the production of cement. These steps are (i) preparing/grinding the raw materials, (ii) producing an intermediary clinker and (iii) grinding and blending clinker with other products to make cement.

Heat consumption of a typical dry process is currently 3.38 GJ/t clinker [WBCSD/CSI, GNR, 2009], where 1.76 GJ/t clinker is the minimum energy consumption for the thermo-dynamical process, about 0.2 to 1.0 GJ/t clinker is required for raw-material drying (based on a moisture content of 3-15 %), and the rest are thermal losses [WBCSD/CSI, ECRA, 2009]. This amount (3.38 GJ/t clinker) is a little more than half of the energy consumption of the wet process (6.34 GJ/t clinker [WBCSD/CSI, GNR, 2009]). According to the BREF (6) [BREF, 2013], the best available value for production of clinker ranges between 2.9 and 3.3 GJ/t (under optimal conditions). It is noted that these values have been revised recently, as in the first version of the BREF document consumption of 3.0 GJ/t clinker was proposed (based on a dry-process kiln with multi-stage preheating and pre-calcination). This broadening of the energy consumption range for clinker production is due to the recognition that there is a realistic difference between short term and annual average values of 160-320 MJ/t clinker, depending on kiln operation and reliability (e.g. number of kiln stops) [Bauer and Hoenig, 2009]. Average heat consumption of the EU industry was 3.74 GJ/t clinker in 2010 [WBCSD/CSI, GNR, 2014]. The average thermal energy value in 2030 can be expected to decrease to a level of 3.3-3.4 GJ/t clinker. However, without impairing efficiency these specific data can be higher if, for example, additional waste heat has to be generated for the purpose of cogeneration of electrical power [WBCSD/CSI, ECRA, 2009]. The percentage of the dry process use in the EU cement industry production has increased from 78 % in 1997 to 90 % in 2007 [BREF, 2013] [CEMBUREAU, 1999]. In the rest of the world this process is progressively gaining ground but not at the same pace. The general trend is towards a progressive phasing out of wet-process facilities; nevertheless, individual cases will provide remarkable exceptions to this trend [Grydgaard, 1998] [Kapphahn and Burkhard, 2009].

The current average of electricity consumption in the EU is 117 kWh/t cement [WBCSD/CSI, GNR, 2014], most of it (around 80 %) consumed for grinding processes. The main users of electricity are mills (grinding of raw materials, solid fuels and final grinding of cement), that account for more than 60 % of electricity consumption [WBCSD/CSI, ECRA, 2009], and exhaust fans (kiln/raw mills and cement mills), which together with mills account for more than 80 % of electrical energy usage [CEMBUREAU, 2006]. However, energy efficiency of grinding is typically only 5-10 % [Taylor et al., 2006]. From 1990 to 2010 the global weighted average of electricity consumption of the participants in the project 'Getting the numbers right' (GNR) [WBCSD/CSI, GNR, 2014] has increased from 114 kWh/t cement to 117 kWh/t cement

(6) BREFs are the main reference documents on Best Available Techniques. They are prepared by the European Integrated Pollution Prevention and Control (IPPC) Bureau and are used by competent authorities in Member States when issuing operating permits for the installations that represent a significant pollution potential in Europe.

CO_2 emissions from the cement industry in the EU peaked in 2007 with 173.6 Mt CO_2 [Ecofys, 2009], whereas in 2008 CO_2 emissions were back down to 2005 values (157.4 Mt CO_2 in 2005 and 157.8 Mt CO_2 in 2008 [Ecofys, 2009]). From 2005 to 2011 specific CO_2 emissions hardly changed (around 0.63 tCO_2/t cement), therefore, EU CO_2 emissions in 2011 (around 124.7 Mt CO_2) [WBCSD/CSI, GNR, 2014] were a direct consequence of the sharp decrease in cement production.

B.3 Market and industry status

EU-27 cement production in 2006 (267.5 Mt) represented 10.5 % of total world production and decreased to 5.6 % of world production in 2011 (195.5 Mt) [BREF, 2013; CEMBUREAU, 2013]. Figure 44 shows the world cement production in 2012, by region and main countries. CEMBUREAU, The European Cement Association, represents the national cement industry associations and cement companies of the EU (with the exception of Cyprus, Malta and Slovakia) plus Norway, Switzerland and Turkey. Based on ICR Research [CemNet, 2014], overall EU consumption per capita in the future can be expected to remain around 350 kg per capita, in spite of the fact that there will be differences among countries.

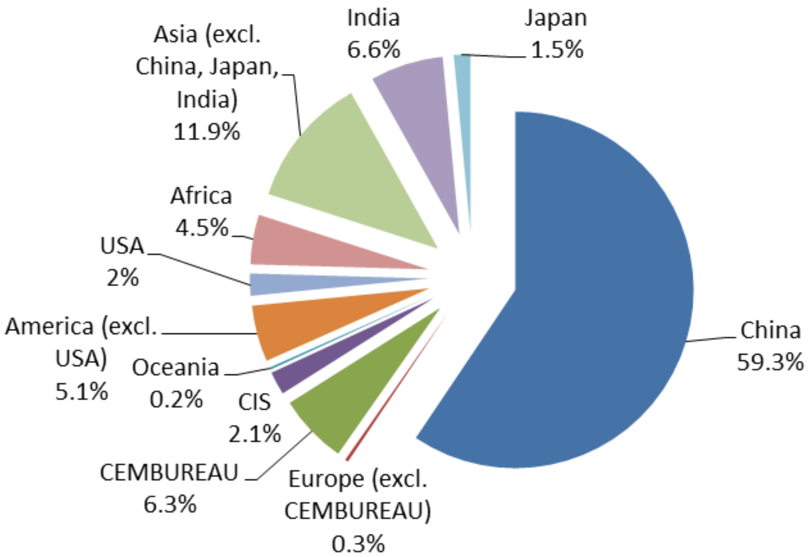

Figure 44: Percentage of world cement production in 2012. main countries [CEMBUREAU, 2013]

Three out of the five world's largest cement producers are based in EU-27: Lafarge (France), HeidelbergCement (Germany) and Italcementi (Italy). The other two big ones are Holcim (Switzerland) and Cemex (Mexico) [BREF, 2013]. This means that the European cement industry has a truly global presence enjoying a market share of 95 % in Europe and 70 % in North America [IEA, 2008]. In addition to the production of cement, these companies have also diversified their activities in other sectors of the building materials.

The recent economic downturn has affected severely the amount of cement imported while keeping the cement exported almost unaltered, as can be seen in Figure 45. These facts could be explained by the observation [CemNet, 2014] that in some markets selling prices are linked to capacity utilisation.

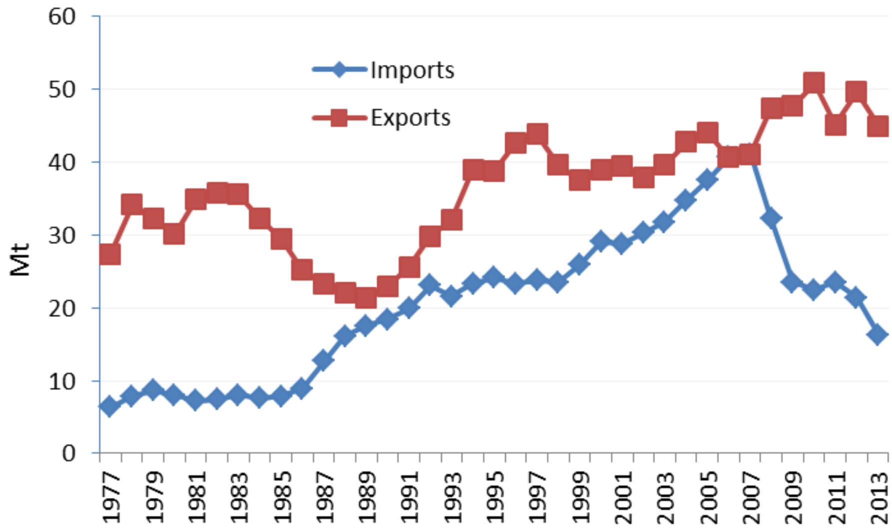

Figure 45: Total (Mt) cement and clinker traded by CEMBUREAU countries (including intra-traded flows) [CEMBUREAU, 2013]

Also the countries of origin for the imports from non-EU countries have changed considerably in the last 10 years, as seen in Figure 46.

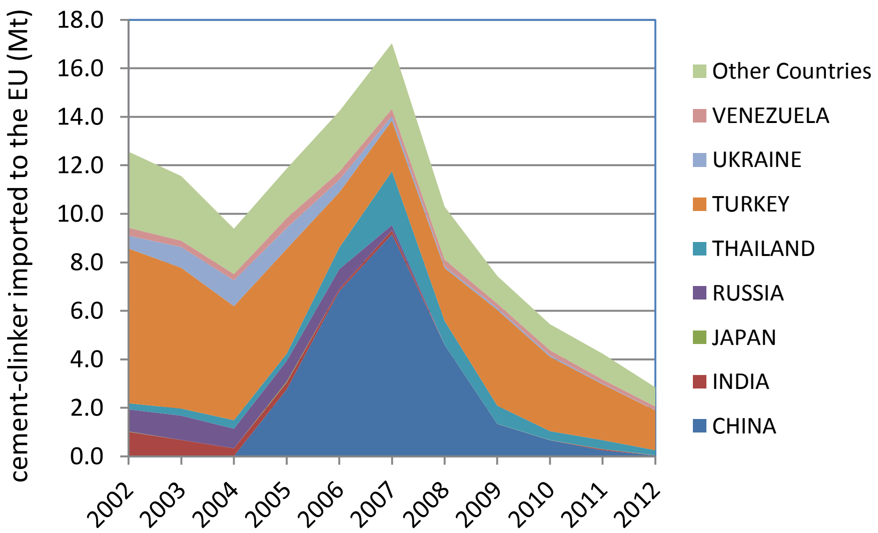

Figure 46: Country of origin of imports into the EU-28 of cement and clinker (excluding intra-traded flows) [Eurostat, 2014a]

The world cement industry has an overcapacity of 1 515 Mt (out of a global capacity of 5 245 Mt in 2012). The Chinese overcapacity in 2012 (around 730 Mt) was two times the total production capacity of the EU of 317 Mt [TPL, 2013]. In 2012 the overcapacity in the EU amounted to around 140 Mt. The Egyptian and Ukraine overcapacity was one order of magnitude lower than EU's (around 10 Mt). It is worth mentioning that the Egyptian capacity (65 Mt) was three times the Ukraine capacity (19.3 Mt). It is also noteworthy that in 2012 only Ukraine out of all the countries considered in this study had a load factor similar to the EU (56 %); the load factor of the rest of countries was higher than the world average of 73 % [TPL, 2013].

B.4 Research protocol

This document follows a bottom-up approach to assess the different costs of the manufacturing processes; this bottom-up approach is based on the information at facility level provided by the Global cement database [WBCSD/CSI, GNR, 2014]. The facilities covered in this study fall with the class 23.51 of the NACE Rev. 2 classification. This class includes the manufacture of clinker and hydraulic cements, including Portland, aluminous cement, slag cement and superphosphate cements.

An alternative bottom-up approach could be based on modelling the performance of the facilities based on the technologies installed and the performances recorded in the bibliography for those technologies. One insurmountable difficulty in this case is that the most complete database with global information about technologies [CEMBUREAU, 2002] has not been updated since its last edition in 2002. Although for countries with a small number of facilities that information could be complemented with the information from the Global Cement Report [TPL, 2013], this is not feasible for countries with a much larger number of facilities. Moreover, in this alternative approach, there would be discrepancies between possible estimations and the values from the field.

Therefore, the basic source of information about the performance of individual facilities in this document comes from the Global cement database [WBCSD/CSI, GNR, 2014]. At the time of writing, the most recent information released refers to 2012. To provide a glimpse of temporal variability, the estimations are also provided for 2011. The indicators used are: clinker-to-cement ratio (indicator 339 in the database), electricity consumption (indicator 3312b), thermal energy consumption (indicator 339a), and the percentage of thermal energy from fossil waste, conventional fuel and from biomass (indicators 3310, 3311 and 3312). To represent the lower and highest production cost, this document will follow the approach of combining the values that produce the lowest and highest costs reported in the benchmarking curves of these indicators. The values used are detailed in Section B.6.

Table 17: Number of facilities in 2012 and degree of coverage of the database of getting the number right of the Cement Sustainability Initiative [TPL, 2013; WBCSD/CSI, GNR, 2014]

	Number of plants in the Global cement database	Total number of plants in the country/region	Coverage (% of cement production, 2012)	Production Capacity Mt Cement
Africa	68	183	44	235
Algeria	4	14	21	20
Egypt	10	23	59	65
CIS	21	96	21	134
Ukraine	6	13		19
China	78	3 900	4	2 950
EU	303	341	94	317

The indicators used for Algeria and Egypt correspond to those reported for Africa in the database. The North African plants in the database (Morocco (13), Algeria (4), Tunisia (2) and Egypt (10)) represent 40 % of the total African plants in the database (68). Therefore it is plausible to assume that the performance of African plants cover the corresponding performance of North African plants. We will also use the overall performance of the plants of CIS countries to account for the performance of Ukrainian plants. In this case, the database contains almost half of Ukrainian plants (see Table 17). In terms of numbers, Ukrainian plants represent almost 30 % of the 21 plants of CIS countries included in the database.

The average of the clinker-to-cement ratio in China has been taken from the Chinese almanac (p. 5) [China almanac, 2011], and the lowest and highest values have been assumed similar to the lowest and highest values in the facilities/countries under study. Despite the limited coverage of Chinese cement production, the Global cement database is the most complete source of information about the global performance of the industry. Moreover, for China, the variability observed in the values reported is relatively low. This, together with the agreement found in Section 7.3 between the costs obtained for the Chinese industry and its prices, drives us to conclude positively about the rightness of the use of this information for the purpose of this document.

In order to avoid any distortion of the cost of capital in different regions of the world, interest and depreciation of the equipment are excluded from the operating cost estimations.

B.5 Prices of energy and raw materials

Table 18 summarises the costs of the energy used in this report. It only contains the values needed to estimate the energy cost of cement production.

Table 18: Prices of energy used for the average cement manufacturer in 2012 [IEA, 2014a; IEA, 2014b; China almanac, 2011; CEMBUREAU, 2014; Neuhoff et al., 2014; CEMBUREAU, 1999b; UNIDO, 2010]

All values in EUR/GJ		Algeria	China	Egypt	Ukraine	EU
Electricity	2011	7.6	17.3	8.6	9.7	21.7
	2012	7.1	18.2	10.4	10.2	23.1
NG	2011	3.7	5.5	2.2	5.9	10.1
	2012	3.5	5.5	2.7	7.4	11.1
Coal	2011		2.9		4.3	4.3
	2012		2.9		4.8	4.8
Petroleum coke	2011					3.2
	2012					3.6
Residual fuel oil	2011	13.3	13.3	13.3	12.1	13.3
	2012	15.3	15.3	15.3	13.9	15.3
Fuel oil	2011	18.6	18.6	18.6	13.3	18.6
	2012	21.3	21.3	21.3	15.3	21.3
Alternative fuel waste	2011					-0.7
	2012					-0.7
Biomass	2011					1.6
	2012					1.6

For the EU, the electricity and natural gas prices come from the values reported by [Eurostat, 2014b] for consumption bands 'if' and 'i3', respectively. To represent the highest and lowest costs from a manufacturer consuming the extremes amounts of electricity we have also used the prices of electricity of bands 'ig' and 'ie' that can be read in Table 19.

Table 19: Electricity prices in the EU for different bands of consumption in 2011 and 2012 [Eurostat 2014b]

	Electricity price EUR/MWh	
	2011	**2012**
band Ig (>150 000 MWh)	64.7	69.6
band If (70 000 MWh-150 000 MWh)	78.0	83.0
band Ie (20 000 MWh-70 000 MWh)	86.9	92.2
band Id (2 000 MWh-20 000 MWh)	95.1	102.1
band Ic (500 MWh-2 000 MWh)	107.5	112.7

The prices for natural gas and electricity for the rest of countries come from the information gathered to produce the first working document about the iron and steel industry (from World Steel Dynamics). The coal price for the EU and Ukrainian cement industry come from [IEA, 2014a]. The value in the EU has been obtained weighting the coal prices according to the cement production. The cost of coal for the Chinese industry comes from [China almanac, 2011].

The price used for the residual fuel oil in all countries but Ukraine is the same as the price in the EU [IEA, 2014b]. The value used for Ukraine comes from the data provided by IHS for the working document of the chemical industry [IHS, 2014]. Also, to estimate the price of fuel oil, we have applied the same ratio between fuel oil to heavy fuel oil price as in the IHS data [IHS, 2014].

The price estimated for the petroleum coke is based on the most competitive substitute of petcoke [CEMBUREAU, 2014], that is the US steam coal, priced at 30-40 % discount for calorific content against petroleum coke.

Regarding alternative fuels, according to [Neuhoff et al., 2014], across the EU fossil fuel wastes (waste oil, tyres, plastics, solvents, impregnated saw dust, mixed industrial waste and other fossil-based wastes) are often accepted for co-incineration with payment of a service fee of around 10 EUR/t waste, which could increase to 100 EUR/t waste for difficult hazardous materials. The price in Table 18 uses a price of 10 EUR/t and an energy content of 26 GJ/t waste [CEMBUREAU, 1999b]. For the price of the biomass we have used the upper value of the range provided in [UNIDO, 2010].

For all countries, as price of the limestone, shale, sand, iron oxide and gypsum we have used the values reported in [IEA, 2008] assuming an annual increase of 0.5 % [Table 20].

Table 20: Prices of raw materials for 2011 and 2012 [IEA, 2008; USGS, 2014; ARTBA, 2011]

	EUR 2011/t	EUR 2012/t
Limestone	3.2	3.3
Shale	1.6	1.7
Sand	53.9	55.6
Iron oxide	53.9	55.6
Gypsum	10.8	11.1
Granulated blast furnace slag	13.5	14.7
Fly ash	31.8	34.7
Clinker substitute	19.4	20.5

The price of the granulated blast furnace slag and fly ash has been taken from [USGS, 2014] and [ARTBA, 2011], respectively. The price of the clinker substitute has been estimated according to the prices reported in the Table 20 (using for the pozzolan and the silica fume the same prices as the ones reported for sand and iron ore respectively) and the percentage content of these materials in the average EU cement production [CEMBUREAU, 2013b].

B.6 Energy and raw materials consumption

As already described in Section B.4 about the research protocol, we have relied on the values reported in the Global cement database [WBCSD/CSI, GNR, 2014]. The values reported for 2012 are provided in Table 21.

Table 21: Thermal energy, electricity, clinker-to-cement ratio and percentage of fuels used in 2012 according to their contribution to the production costs of cement manufacture

	Contribution to the cost	Thermal energy MJ/t clinker	Electricity kWh/t cement	Natural gas (%)	Heavy fuel Oil (%)	Fuel oil (%)	Coal (%)	Petroleum coke (%)	Waste fuels (%)	Biomass (%)	Clinker to cement ratio
		Ind. 339a	Ind. 3312b	Indicators 3310, 3311 and 3312 and [IEA, 2014c]							Ind. 339
Algeria	Lowest	3 260	35	100							0.45
	Average	3 300	96	100							0.77
	Highest	4 750	125	100							0.90
Egypt	Lowest	3 260	35	100							0.45
	Average	3 300	96	65	21	14					0.77
	Highest	4 750	125		100						0.90
Ukraine	Lowest	3 140	90				100				0.70
	Average	5 080	121	45	5		50				0.80
	Highest	6 720	140	100							0.82
EU	Lowest	3 150	50	0	0	1	9	16	53	21	0.48
	Average	3 750	109	1	1	1	22	39	25	11	0.72
	Highest	5 400	140	1	2	1	35	61	0	0	0.86
China	Lowest	3 000	80				100				0.45
	Average	3 300	93	4	1	2	90	3			0.62
	Highest	6 500	106				100				0.90

We use as raw materials consumption the corresponding values reported in [IEA, 2008] for a plant with an annual capacity of 1Mt cement operating at load factor of 90 %, see Table 22.

Table 22: Raw materials annual consumption in a cement producing facility of 1 Mt operating at load factor 90 %

Raw material (t)	
Limestone	1 245 973
Shale	283 974
Sand	7 473
Iron oxide	7 473

This document assumes that each tonne of substitute of clinker has the same percentage as the average cement consumed in the EU (see Table 23). These estimations are based on the average composition and consumption of cements in the EU [CEMBUREAU, 2013b].

Table 23: Percentage composition of the clinker substitute in the average cement consumed in the EU

	Percentage %
BFS	32.5
Silica fume	7.1
Pozzolan	10.6
Fly ash	10.9
Burnt shale	2.8
Limestone	25.2
Gypsum	10.9

B.7 Costs

7.1 Energy cost

Energy costs (in Figure 47 and Table 24) are produced by combining the information of the average energy consumed (Table 21) and the prices of Table 18. The fuel mix used in all countries is quite different; whereas Algeria gets its thermal energy from low-cost natural gas, Egypt, with the same thermal performance, doubles its energy cost due to their use of the much more expensive fuel oil. In China thermal energy consumption is based on the cheapest fuel (coal). The prices of the main fuels (NG and coal) used in Ukraine are lower than the corresponding values in the EU, however the Ukrainian price for NG cannot compete with the lower prices of the fuels mainly used in the EU (coal and petroleum coal). This fact combined with the poor average Ukrainian plant performance (mainly due to their technological choice) makes the cost of Ukrainian thermal energy fourfold the cost in the EU. When including the electrical costs, the cheaper price of Ukrainian electricity results in making their overall energy cost double of the energy costs in the EU.

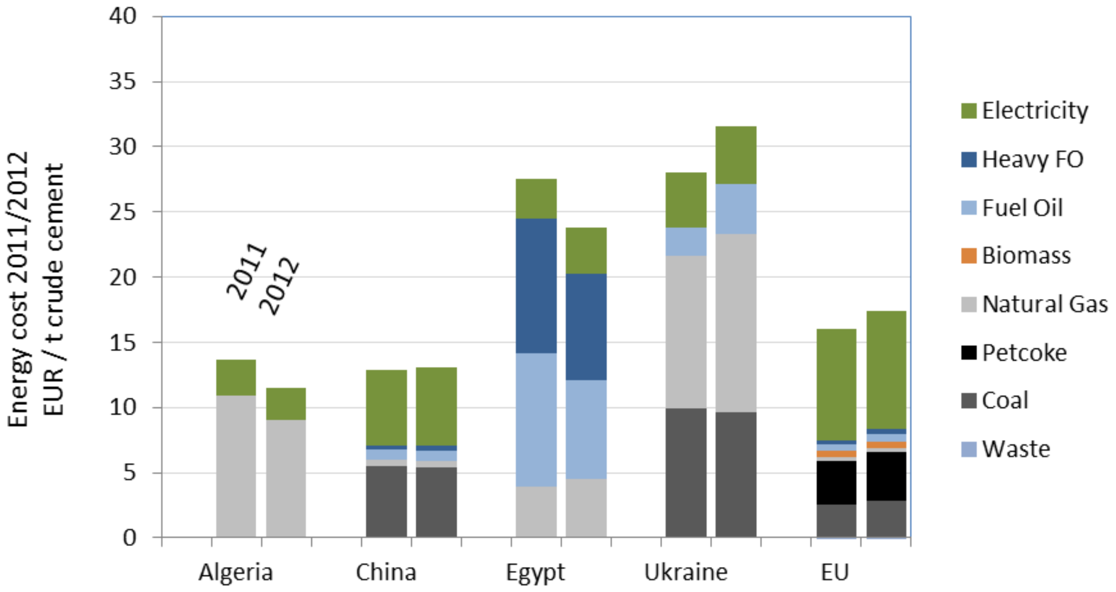

Figure 47: Energy cost in the cement industry in 2011/2012 (EUR/t cement)

The energy cost in Figure 47 and Table 24 is a consequence not only of the energy prices of Table 18, but also of the thermal energy consumption per tonne of clinker and the clinker-to-cement ratio, both in Table 21. For example, although the coal prices in the EU and Ukraine of Table 18 are quite similar, in Ukraine the cost of the coal consumed per tonne of cement is around four times the cost in the EU (see Table 24). This can be explained by the fact that the coal only satisfies 22 % of the thermal demand in the EU and 50 % in Ukraine. Also, specific thermal energy consumption in Ukraine is 35 % higher than in the EU. Moreover, the Ukrainian clinker-to-cement ratio is higher than in the EU. (The substitution of clinker in cement does not require thermal energy consumption associated to clinker production.)

Table 24: Energy cost in the cement industry per tonne of cement in 2011 and 2012

All values in EUR/t cement		**Algeria**	**China**	**Egypt**	**Ukraine**	**EU**
Electricity	2011	2.7	5.8	3.1	4.2	8.5
	2012	2.5	6.1	3.6	4.4	9.0
NG	2011	10.9	0.5	3.9	11.6	0.3
	2012	9.0	0.5	4.5	13.6	0.3
Coal	2011		5.5		10.0	2.5
	2012		5.4		9.7	2.8
Petroleum coke	2011					3.4
	2012					3.8
Residual fuel oil	2011		0.3	10.2		0.4
	2012		0.3	8.2		0.4
Fuel oil	2011		0.8	10.3	2.2	0.5
	2012		0.9	7.5	3.9	0.6
Alternative fuel waste	2011					-0.3
	2012					-0.3
Biomass	2011					0.5
	2012					0.5
Total cost of thermal energy	2011	10.9	7.1	24.4	23.8	7.3
	2012	9.0	7.0	20.2	27.1	8.1

7.2 Raw materials and other costs

In the same way as the energy costs, the raw materials costs can be obtained by multiplying consumption with prices (Table 22, Table 23 and Table 20).

Under the 'other costs' we integrate the same costs as in [IEA, 2008], see Table 25. This breakdown corresponds to a 1 Mt European cement facility. We updated the costs to EUR 2011 and EUR 2012 assuming an annual increase of 0.5 % [Wang et al., 2014].

Table 25: Breakdown of the term 'other costs' for the reference cement plant [IEA, 2008]

	2011 MEUR/Mt	2012 MEUR/Mt
(1) Maintenance	11.3	11.6
(2) Operating labour	3.9	4.0
(3) Supervision	0.7	0.7
(3) Administration and overhead	1.4	1.5
(2) Local rates	2.9	3.0
(3) Insurance	2.9	3.0
Total	23.1	23.7

(1) Value varying with the plant size
(2) Values (assumed) varying per country proportional to the labour costs in another energy-intensive industry in those countries

(3) Values (assumed) constant for all countries

For the non-European countries we assume the same specific values for supervision, administration and overheads and insurance. The labour costs used for each country come from WSD applying to all countries the same ratio as the one needed to keep the European labour cost provided by IEA [IEA, 2008].

It is worth noticing that maintenance cost is almost half the value under the heading 'other cost'. This concept is highly dependent on the facility size. Moreover, there is a large variation among the largest and smallest facilities in the countries considered. Therefore, we have adjusted the maintenance cost as function of the capacity according to [Alsop, 2005]. The maintenance costs obtained agree with the range provided in [OSCG, 2010] (among 5 to 20 % of overall operating expenses or absolute costs between USD 4–15 per tonne of cement). Annual expenses represent approximately 2–4 % of the asset value or replacement value of a plant.

The resulting values for 'other costs' (excluding the maintenance cost) and the maintenance cost are in Table 26.

Table 26: Sizes of the cement plants by their contribution to the estimated maintenance cost and labour and other costs in 2011 and 2012

	Contribution to the specific costs	Cement capacity (Mt)	Maintenance cost (EUR/t cement)		Labour and others costs (excluding maintenance) (EUR/t cement)	
			2011	2012	2011	2012
Algeria	Lowest	1.9	8.5	8.7	5.8	6.0
	Average	1.1	9.8	10.1		
	Highest	0.5	12.7	13.1		
Egypt	Lowest	7.0	5.9	6.1	5.8	6.1
	Average	2.4	8.0	8.2		
	Highest	1.0	10.1	10.3		
Ukraine	Lowest	4.0	6.9	7.1	5.0	5.2
	Average	2.0	8.4	8.7		
	Highest	0.4	13.6	13.9		
EU-28	Lowest	4.6	6.6	6.8	10.6	10.9
	Average	1.0	10.2	10.5		
	Highest	0.1	19.4	19.9		
China	Lowest	12.0	5.1	5.2	5.7	6.0
	Average	4.5	6.7	6.9		
	Highest	0.3	13.9	14.3		

7.3 Overall costs

Figure 48 summarises the results obtained in Section 7.1 about the energy costs and Section 7.2 regarding the cost of raw materials and other costs. Figure 48 shows that, in some countries, the percentage represented by the costs of energy, raw materials and labour is similar to the indicated in [Lasserre, 2007] (29 % energy, 27 % raw materials, 32 % labour and 12 % depreciation). It is noted that our cost estimation excludes the capital cost (depreciation) and the profit. Regarding the profit, according to the BREF of the industry [BREF, 2013], it is around 10 % as a proportion of turnover (on the basis of pre-tax profits before interest repayments).

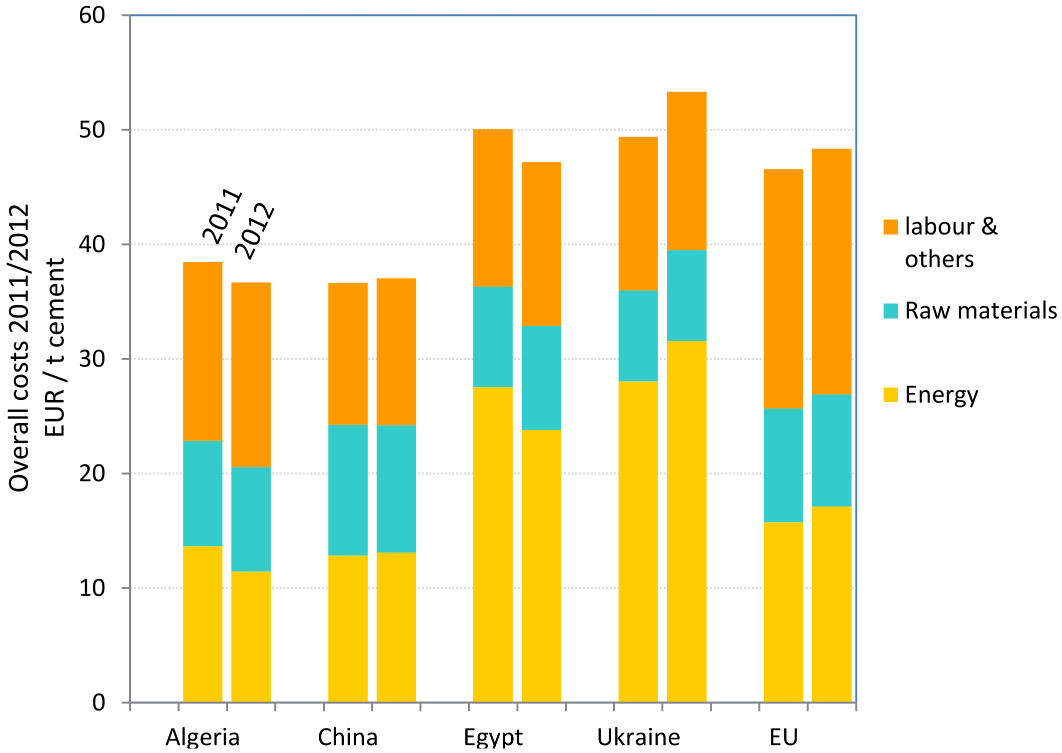

Figure 48: Summary of total cement industry costs in 2011 and 2012

According to Figure 47 and Figure 48, the energy cost is much higher in two of the countries analysed (Ukraine and Egypt) than in the EU. When adding the estimations of the other components of the cost, the total cost in the EU in 2012 (48 EUR/t) ends up between the Egyptian cost (47 EUR/t) and Ukrainian cost (53 EUR/t). In any case, the breakdown of the energy cost provided in Figure 47 reveals that the weight of the electricity cost in the EU (around half of the total energy invoice) is not reproduced in any other of the countries analysed. The electricity cost represents around 7 % of the total cement cost in Algeria, Egypt and Ukraine, 17 % in China and 19 % in the EU. Regarding the thermal energy cost, the mix of fuels in the EU and energy performance make this cost similar to Chinese and Algerian ones (8.1, 7.0 and 9.0 EUR/t, respectively) and much lower than the thermal energy cost of Egyptian and Ukrainian cement.

Figure 49 and Figure 50 represent the specific costs in each country. In these figures each curve represents a component of the cost, for each one of them the countries are ranked according to their increasing average costs. Each vertical line joins the minimum and maximum cost estimated for each country (according to their different performances and prices).

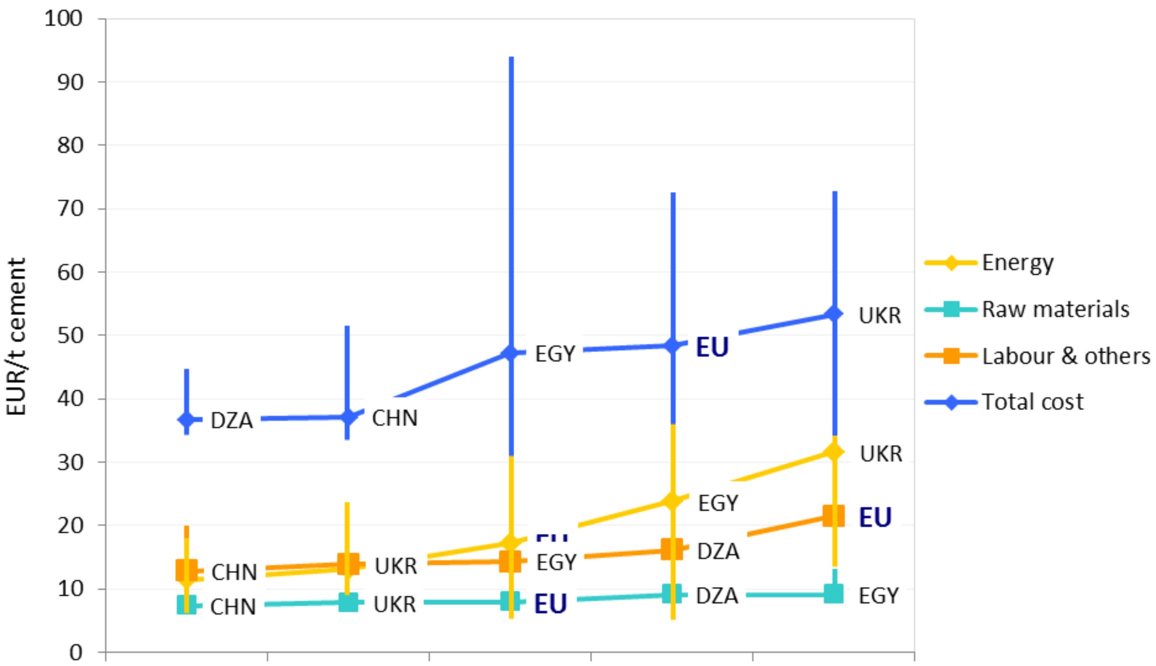

Figure 49: Average cost-curves of cement production in 2012 and intervals encompassing the maximum and minimum estimated costs

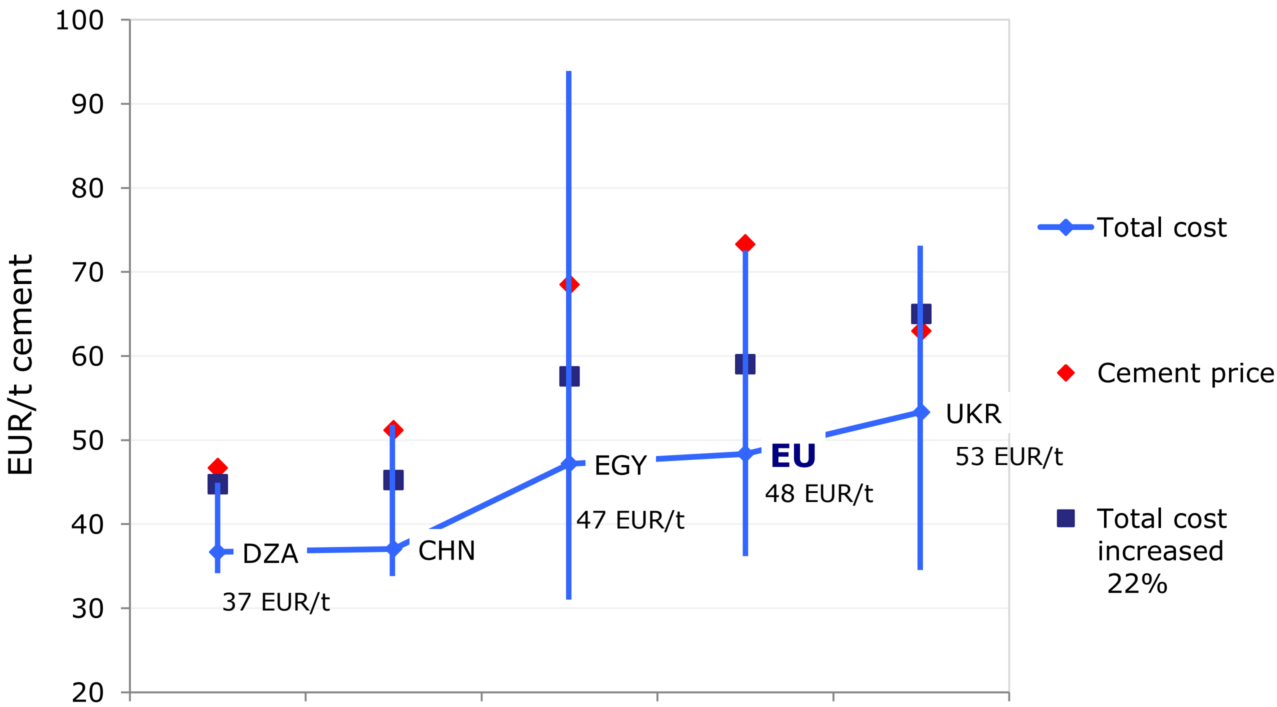

Figure 50: Average cost-curve of cement production in 2012, cement price and intervals encompassing the maximum and minimum estimated costs

The values of the average total costs in Egypt (47 EUR/t), the EU (48 EUR/t) and Ukraine (53 EUR/t) are quite similar. However, the variability between the best are worst performers is much higher in Egypt than in the EU and Ukraine; this is due to the higher cost of the main fuel used in Egypt (fuel oil).

Although the average costs of Chinese and Algerian production (around 37 EUR/t for both countries) are clearly lower than in the rest of countries, the lowest production costs of all countries show very low variability (from 30 to 36 EUR/t), meaning that in all countries the most competitive producers are able to produce the cement with relatively similar costs.

Note that the costs described are the main component of ex-factory prices; they do not include shipping, handling, taxes or customs. These costs exclude additional components of the price such as the capital costs (interest and depreciation) and benefit. Transport costs, not included in this analysis, are around EUR 10 per tonne of cement per 100 km by road and around EUR 15 to cross the Mediterranean Sea [Hourcade et al., 2007].

Even underlining that some components of the cement price are excluded of this costs estimation, we provide the cement prices in Figure 50 to check the validity of the costs. In 2012 the price of the production in the EU was 73.3 EUR/t [Eurostat, 2014c]. The latest prices (in 2011) reported in the INDSTAT database [UN, 2014] were 51.2 EUR/t in China and 63.0 EUR/t in Ukraine. In 2012, the Global Cement Report [TPL, 2013] mentions prices of 46.7 EUR/t in Algeria and 68.5 EUR/t in Egypt.

The results of Figure 47, Figure 48 and Figure 50 show that although the difference in the estimated average cost is small among Egypt, Ukraine and the EU, there are clear differences in the weight of the different components of their costs (mainly energy), and between the costs of this three countries/regions and the Algerian and Chinese cement cost.

Incrementing 22 % the estimated costs to include roughly the effect of the capital costs and profit, the result agree pretty well with the cement prices in Algeria and Ukraine, and also with the Chinese cement price when using 44 EUR/t for 2010 [China almanac, 2011]. For Egypt and the EU, those incremented costs are halfway the cement prices and the estimated average total costs.

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ANNEX C. Production costs from the chemical industry in the EU and in third countries

C.1 Introduction

The purpose of this annex is to provide the results of a combined research and data collection exercise, using public and, where possible, commercial and industry data, aiming to establish different parameters that affect the cost and production process of the chemical industry.

The availability and accuracy of information has been a key factor determining the final list of countries included in the collection of data. For the chemical industry, this list includes Russia, Saudi Arabia, Ukraine, the United States and the EU as a whole. In addition, due to the complexity of this industry, it was agreed to limit this study to four of the products that serve as building blocks for the whole chemical industry: ammonia, methanol, ethylene and propylene.

The second and third sections of this annex are devoted to describing manufacturing processes and provide a glimpse of the market status, whereas the fourth section details the research protocol followed in this report. The fifth section contains the prices of energy and raw materials used, and the sixth section provides consumption of energy and raw materials. All this information is combined in the seventh section to produce an estimate of the production costs.

C.2 Manufacturing routes

As mentioned earlier, the study is limited to four main chemical products, namely ammonia, methanol, ethylene and propylene. For this reason this section will include the descriptions of only these chemical products.

Ammonia is synthesised from nitrogen and hydrogen according to the Haber–Bosch process:

$$N_3 + 3\ H_2 \leftrightarrow 2\ NH_3 \qquad \text{(reaction 1)}$$

Nitrogen is usually fed into the ammonia production process as air, while hydrogen is derived either directly via the processes described below or as a by-product from various feedstocks. The feedstocks used worldwide are shown in Figure 51. The reaction takes place over a catalyst, commonly iron that may be promoted with aluminium, potassium and/or calcium [Liu, 2013]. A ruthenium-based catalyst developed in the late 1990s is more active than the iron-based materials and offers significantly improved synthesis efficiency by lowering the synthesis pressure. The activity of cesium-promoted ruthenium catalysts has been reported to be three to four times higher than that of the iron catalyst under specific conditions, while the activity of barium-promoted ruthenium catalysts an order of magnitude higher than the iron catalyst under specific conditions [Bielawa et al., 2001].

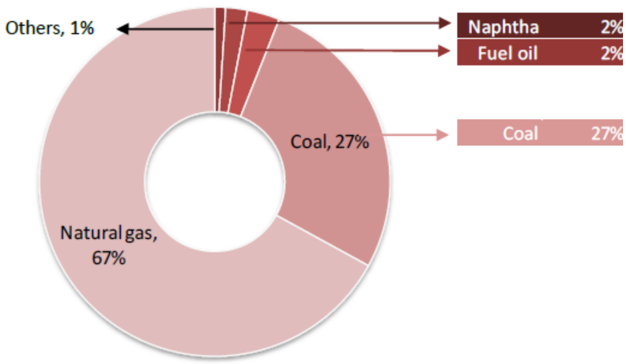

Figure 51: World ammonia production by feedstock type (2008) [Carbon Counts, 2010]

Depending on the type of feedstock used, hydrogen, and therefore ammonia, is produced mainly by two methods: (1) steam reforming in the case of light hydrocarbons, such as natural gas or light naphthas, and (2) partial oxidation used mainly in the case of heavy oils or solid carbonaceous materials. When natural gas is used as feedstock, the following two reactions take place (steam reforming):

$$CH_4 + H_2O \leftrightarrow CO + 3H_2 \qquad \text{(reaction 2)}$$

$$CO + H_2O \leftrightarrow CO_2 + H_2 \qquad \text{(reaction 3)}$$

while in partial oxidation:

$$CH_4 + \tfrac{1}{2}O_2 \leftrightarrow CO + 2H_2 \qquad \text{(reaction 4)}$$

Simplified diagrams of these methods are shown in Figure 52. A third method for producing hydrogen, the autothermal reforming, is the combination of the two previous methods. In autothermal reforming steam is added to catalytic partial oxidation, resulting in significant advantages: the process can stop and start rapidly, contrary to steam reforming, and can produce larger amounts of H_2 than from partial oxidation alone [Holladay et al., 2009].

In the case of steam reforming, typical consumption lies between 22 and 24 GJ/t_{NH3} for feedstock and 5.4 and 9 GJ/t_{NH3} for fuel. In the case of partial oxidation, typical consumption is around 28.8 GJ/t_{NH3} for feedstock and between 5.4 and 9 GJ/t_{NH3} for fuel, while autothermal reforming consumption is about 24.8 GJ/t_{NH3} for feedstock and 3.6-7.2 GJ/t_{NH3} for fuel [EFMA, 2000]. Thus, conventional reforming has the lowest feedstock consumption and partial oxidation the highest, while fuel demand is lowest in the case of autothermal reforming. The fuel requirements refer to an efficient stand-alone plant with no energy export and no other import than feedstock and fuel.

Steam reforming using natural gas is by far the least expensive and most popular method of producing hydrogen for ammonia synthesis, and it is the method used almost exclusively in the countries of interest for this study and around the world.

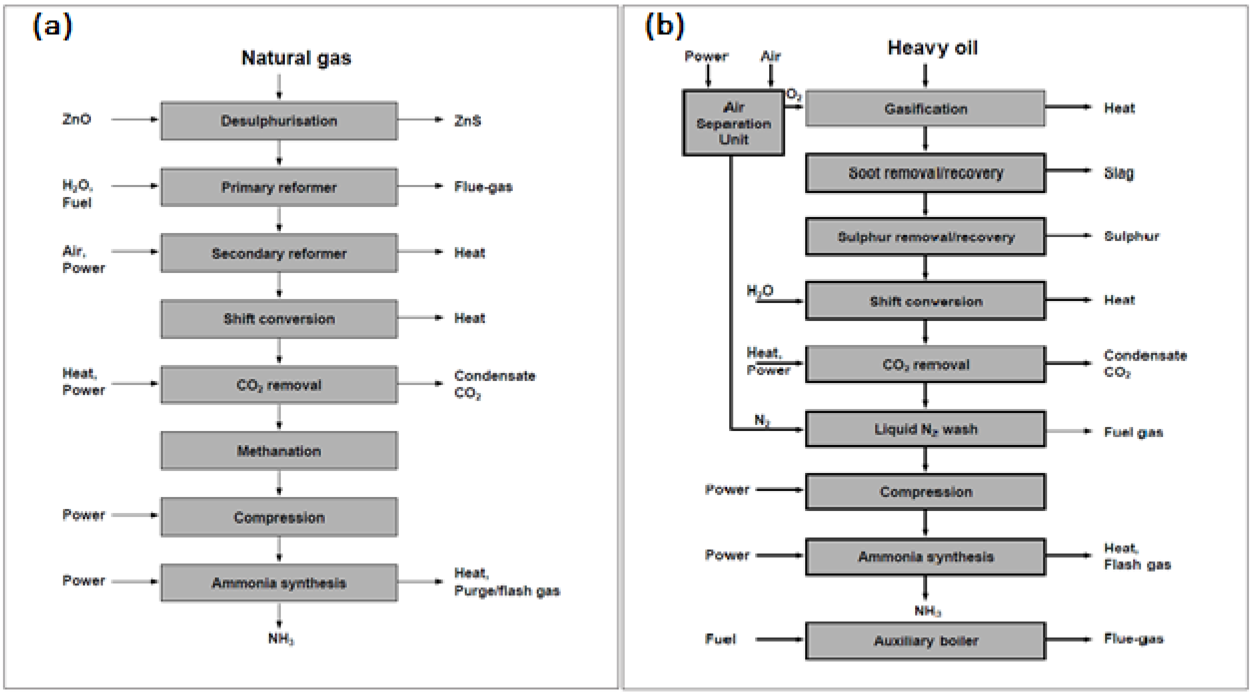

Figure 52: Diagram of (a) the steam reforming process and (b) the partial oxidation process [EC, 2007]

Methanol is produced mainly by the Fischer–Tropsch process, where pressurised synthesis gas (mixture of H_2 and CO) reacts in the presence of a catalyst:

$$CO + 2\,H_2 \rightarrow CH_3OH \qquad \text{(reaction 5)}$$

$$CO_2 + 3\,H_2 \rightarrow CH_3OH + H_2O \qquad \text{(reaction 6)}$$

$$CH_4 + ½\,O_2 \rightarrow CO + 2\,H_2 \rightarrow CH_3OH \qquad \text{(reaction 7)}$$

Synthesis gas is produced, as in the case of ammonia, by steam reforming, partial oxidation or a combination of both processes (combined reforming). Combined reforming produces synthesis gas with a more balanced ratio of hydrogen to carbon oxides (CO and CO_2) [IPCC, 2006].

The first catalysts used in the methanol synthesis were ZnO/Cr_2O_3, operated at 350 ^oC and 250-350 bar, but they have been abandoned since the introduction of $Cu/ZnO/Al_2O_3$ that operate at lower temperatures (220-275 ^oC) and lower pressure (50-100 bar). The synthesis of the catalyst usually varies depending on the manufacturer [Spath & Dayton, 2008].

Due to production economics, the primary feedstock for syngas is natural gas (58 % of the world's methanol production in 2013), but it can be produced also from naphtha, petroleum residues, coal and, at least potentially, from methane-containing gases from landfills. It is worth mentioning that the main feedstock in the new plants built in China is coal. The feedstock required depends on the process used. In the case of steam reforming of natural gas it is estimated to be around 33.4 $GJ/t_{methanol}$ and 36.5 $GJ/t_{methanol}$, with and without primary reform respectively. On the other hand, in the case of partial oxidation the feedstock required is 37.15 $GJ_{oil}/t_{methanol}$, 71.6 $GJ_{coal}/t_{methanol}$ or 57.6 $GJ_{lignite}/t_{methanol}$ [IPCC, 2006]. The reaction-producing methanol is highly exothermic, and a major challenge is to remove the excess heat in order to shift the equilibrium towards the products and avoid side reactions and catalyst sintering [Spath & Dayton, 2008].

Within the last decade some new types of large methanol plants, known as 'mega-methanol' plants, have been built, particularly in regions rich in natural gas such as the Middle East. These plants offer significant economies of scale and are able to produce methanol at a lower cost [Olah et al., 2009]. An example of such a commercial process is the Lurgi MegaMethanol process, developed for methanol plants with capacities greater than 1 million tonnes per year [Air Liquide, 2013].

Ethylene — ethane according to the International Union of Pure and Applied Chemistry (IUPAC) — and propylene — propene according to IUPAC — are the main light olefins. The primary process for production of light olefins is steam cracking, known also as thermal pyrolysis. Steam cracking is a complex process, producing more than one product and accepting a variety of hydrocarbons as feedstock, ranging from natural gas liquids ([7]) (ethane, propane, butane) to petroleum liquids (naphtha and distillate fuel oil). Each feedstock results in a characteristic co-product composition, with the light feedstocks resulting in lower co-product yields than the heavier ones. The ethylene and propylene yields vary between 24-81 % and 1.5-25 % respectively, depending mainly on the feedstock type and operating conditions (Table 27). Steam cracking is a mature process with little change in more than 50 years of practice.

The choice of feedstock depends on market factors and the availability of supplies. In 2012 naphtha and condensates provided about 70 % of the feed to the ethylene crackers in the EU, 17 % came from ethane, propane and butane and the rest from gasoil and other sources [Petrochemicals, 2014]. The final product yields depend on the feedstock and the cracking severity (the conditions used during cracking, mainly the temperature). Typical product yields for different feedstocks for an ethylene plant with 453 kt per year capacity are shown in Table 27.

Depending on what is considered as final product, there are different ways to express consumptions and emissions in the case of steam cracking. If ethylene is the final product of the process, all energy and feedstock used is allocated only to it, and all other co-products are hence energy and feedstock neutral. According to Table 27 and depending on the feedstock used, feedstock consumptions for steam cracking are 1.235 $t_{ethane}/t_{ethylene}$ or 4 $t_{gasoil}/t_{ethylene}$ or 2.94 $t_{naphta}/t_{ethylene}$. Energy use varies between 15 and 25 $GJ/t_{ethylene}$ for ethane, 25 and 40 $GJ/t_{ethylene}$ for naphtha and 40 and 50 $GJ/t_{ethylene}$ for gasoil [IEA, 2007].

([7]) 'Natural gas liquids' (NGLs) is the term used to refer collectively to hydrocarbons heavier than methane present in raw natural gas.

Table 27: Typical product yields (kt) for different feedstocks for a plant with ethylene capacity of 453.6 kt/yr (adjusted from [ACC, 2004]) [8]

Product	Feedstock (kt)				
	Ethane	Propane	Naphtha ([9])	Atmospheric Gasoil	Vacuum Gasoil
Cracking severity	High	Medium to high	Medium to high	Medium to high	Medium
Hydrogen-rich gas (kt)	33	17-21	11-14	12-26.5	17-26
Methane-rich gas (kt)	39.5	263-296.5	199-222	183-196	175-194
Ethylene (kt)	453.6	453.6	453.6	453.6	453.6
Propylene ([10]) (kt)	11	166-293.5	181-260	242.5-283	261
Butadiene (kt)	10	18-32	56-77	76-82	79
Butenes/ Butanes (kt)	4.5	13-22	59.5-128	76-88.5	84
Pyrolysis gasoline (kt)	9	47-71	183-494	294-342.5	299.5
Benzene	4.5	17-26.5	51-84	96-109	109
Toluene	0.5	5-5.5	19.5-71.5	51-54.5	57
C8 Aromatics	0	0	26.5-43	20-43	134
Other	4	25-39	86-295	127-136	
Fuel oil (kt)	0	4.5-10	29.5-51	289-376.5	544-605.5
Total (kt)	561	1 029-1 200	1 173-1 670	1 614-1 822	1 897-1 977
Ethylene yield (%)	81	38-46	27-39	25-28	23-24

Steam cracking is fully meeting the ethylene demand in the EU [Ecofys, 2009], while worldwide it accounts for more than 95 % of ethylene produced. In the United States 62 % of ethylene is produced from steam cracking of ethane and only 8 % from naphtha [IHS, 2014b].

Concerning propylene production, the four commercially proven routes are: (1) steam cracking, (2) fluid catalytic cracking (FCC), (3) propane dehydrogenation and (4) metathesis of ethylene and butylenes. Worldwide about 56 % is obtained as co-product during ethylene production, and about 33 % is produced as by-product of petroleum refining. The remainder is produced from the dehydrogenation of propane and metathesis of ethylene and butylenes [IHS, 2011a]. Metathesis can either be a stand-alone process or be integrated into a steam cracker [Ecofys, 2009]. In the EU steam cracking covers about 70 % of propylene production [Petrochemicals, 2014], but in the United States the majority of propylene is produced by refineries [Chem Technology, 2014].

Propylene (propene according to IUPAC) can be obtained from the petroleum refining through fluid catalytic cracking (FCC). Cracking is used in refineries primarily to produce gasoline and distillate from heavy oils, but it also converts a significant portion of the feed to C_1-C_4 products, including propylene and hydrogen [EC, 2013]. The percentage of propylene produced depends on the operating mode of the FCC: if it is operated in gasoline mode the average propylene yield is about 5 wt% on fresh feed, while if it is

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([8]) Data is representative of relative material balances for an ethylene plant with a capacity of 453 kt per year when feeding one feedstock at the assumed severity conditions. Ethane and propane recycling to extinction is assumed for all feedstock categories.

([9]) The ranges for this category are wide because naphtha is not uniformly defined. There is a tendency in the industry to use light naphthas, so as to use lower-severity conditions and increase the yield of propylene.

([10]) Polymer-grade propylene production is assumed.

operated in propylene mode it can reach up to 20 wt% [Couch et al., 2007]. A simplified flow diagram for fluid catalytic cracking can be found on UOP's website [UOP, 2014a].

The feed in the catalytic cracking unit can be heavy gas oils from the vacuum distillation unit in the refineries or bottom streams from the atmospheric distillation unit. Depending on the feedstock, the process is named either fluid catalytic cracking or residue catalytic cracking, but often units designed for one type of feedstock can also treat some of the others. Utility consumption of catalytic crackers per tonne of product is estimated to be 120-2 000 MJ of fuel, 2-60 kWh of electricity and 5-20 m^3 of cooling water, while concerning the steam the process consumes about 30-90 kg and produces 40-60 kg in the case of fluid catalytic cracking, and in the case of residue catalytic cracking consumption is 50-300 kg and production 100-170 kg [EC, 2013].

Besides producing propylene as a co-product of steam or catalytic cracking, several 'on-purpose' propylene production technologies have been developed. These include olefin metathesis and propane dehydrogenation.

Olefin metathesis is an established method, having been in use for a few decades. Propylene is produced by applying the metathesis reaction for the conversion of a mixture of ethylene and butylene according to the following reaction:

$$CH_2{=}CH_2 + CH_3CH{=}CHCH_3 \leftrightarrow 2\ CH_3CH{=}CH_2 \qquad \text{(reaction 8)}$$

It was originally developed for production of ethylene and butylene from propylene, due to the low demand of the latter, but the reverse direction has become more interesting the recent decades [Mol, 2004]. The process, named olefins conversion technology (OCT), requires two types of catalysts, one metathesis catalyst (usually WO_3/SiO_2) and one isomerisation catalyst (usually MgO) and takes place at > 260 ^oC and 30-35 bar. During recent years there has been an attempt to improve the catalytic system [Mazoyer et al., 2013]. Metathesis technology is also made available by the Institut français du pétrole, named Meta-4 process. Ethylene and butylene react with each other in the liquid phase in the presence of a Re_2O_7/Al_2O_3 catalyst at 35 ^oC and 60 bar [Mol, 2004]. A simplified process flow diagram of the olefins conversion technology can be found in [Mol, 2004].

Propylene via propane dehydrogenation is an endothermic equilibrium reaction, which is carried out in the presence of a heavy-metal catalyst, usually chromium:

$$CH_3CH_2CH_3 \rightarrow CH_3CH{=}CH_2 + H_2 \qquad \text{(reaction 9)}$$

There are several commercial processes available for catalytic dehydrogenation of propane, among them is UOP's Oleflex propane–butane dehydrogenation process, with currently nine units in operation worldwide [UOP, 2014b]. The process is separated into the reactor section, the product recovery section and the catalyst regeneration section. The reaction takes place in a propane–propylene splitter to produce a chemical or polymer-grade polymer product. Unconverted propane is recycled to the reactor section. A simplified flow diagram can be found in [Meyers, 2004].

C.3 Market and industry status

The chemical industry is one of the most diverse, with a wide range of products that can be used in the majority of economic sectors. The global chemical sales for 2013 are valued at EUR 3 156 billion, with the EU chemical industry accounting for EUR 527 billion (16.7 % of the global sales, as can be seen in Figure 53). This is increased to EUR 603 billion if Switzerland, Norway, Turkey, Russia and Ukraine are also included [Cefic, 2014]. In 2012, the sales of the EU chemical industry accounted for 17.8 % of the global chemical sales of EUR 3 127 billion [Cefic, 2013].

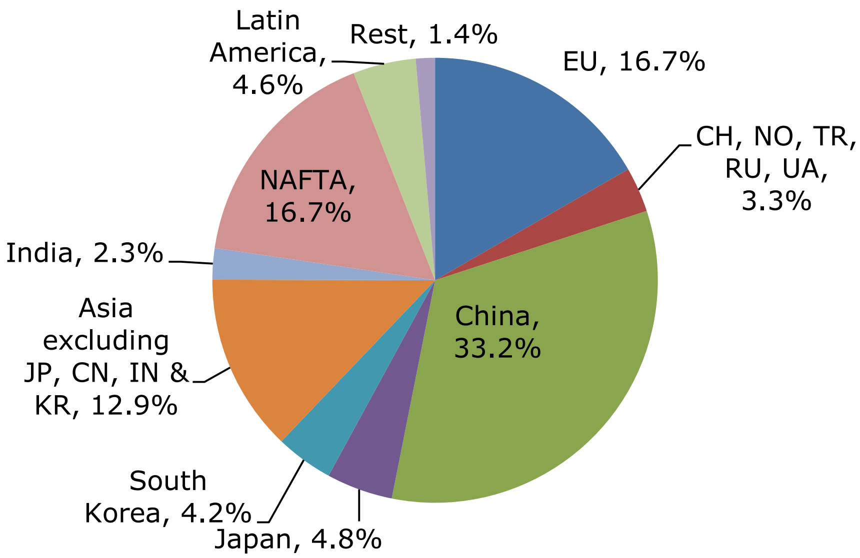


Figure 53: Percentage of chemical sales in 2013 (elaboration from [Cefic, 2014])

Concerning the different major segments of the global chemical industry, Figure 54 shows the distribution of the global chemical shipments. Shipments express the nominal value of products shipped from manufacturing facilities without adjustment for price changes and are equivalent to the term 'turnover' [ACC, 2013]. Basic chemicals, which include inorganic chemicals, bulk petrochemicals, organic chemical intermediates, plastic resins, synthetic rubber and fibres, represent the largest share of the global business of chemistry, with a share in total shipments of 42 % in 2012 [ACC, 2013].

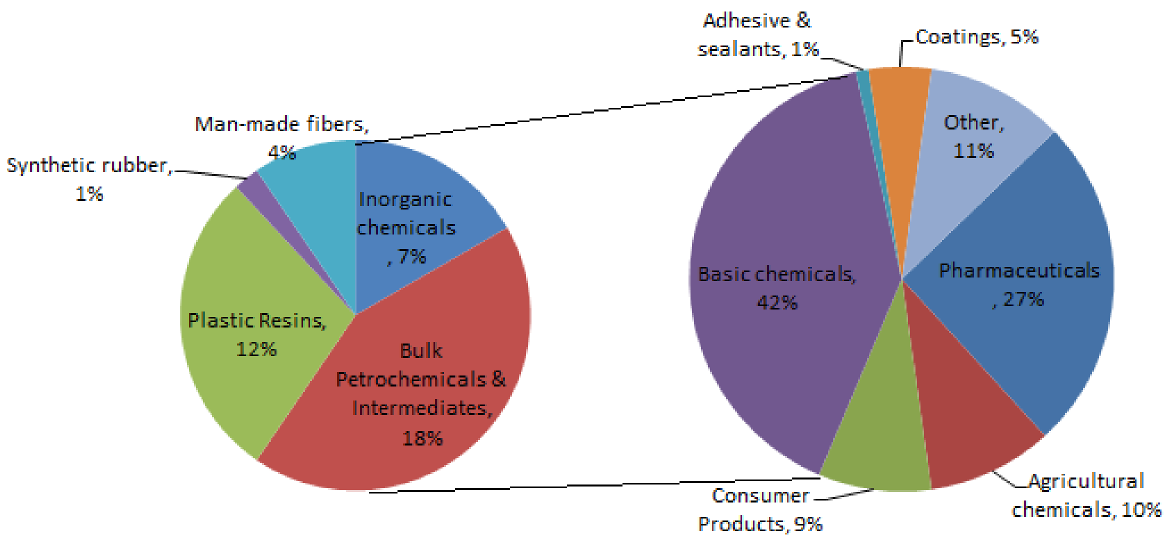


Figure 54: Global chemical shipments by segment as a percentage of the total shipments in 2013 (based on data included in [ACC, 2013])

In the EU the chemical industry represents 1.1 % of EU GDP [EC, 2014b] and it is a mature and rather stable industry, which recovered relatively well from the economic crisis of 2008/2009, with its production level in 2012 being 9 % below the 2008 peak [EC, 2014b]. However, its sales in 2008 (EUR 566 billion) were similar to the sales in 2012 (EUR 558 billion). As already mentioned it accounts for about one fifth of the global chemical sales. However, the EU contribution was 12.7 % lower than ten years earlier, a decrease that can be attributed to the fast growth of the Asian sales (excluding Japan). EU is the leading exporter and one of the leading importers of chemicals in the world, accounting for 41.6 % of the world exports and 34.8 % of imports in 2012 [Cefic, 2013]. The total exports of the EU amounted to EUR 275.4 billion in 2012 and EUR 273.2 billion in 2013, while the total imports amounted to EUR 163.3 and 157.6 billion in 2012 and 2013 respectively [Eurostat, 2014a]. By comparison, in 2012 the United States exports were estimated to be EUR 241.9 billion and imports EUR 240.9 billion, and in Russia imports and exports reached EUR 61 and 51.9 billion respectively [ACC, 2013].

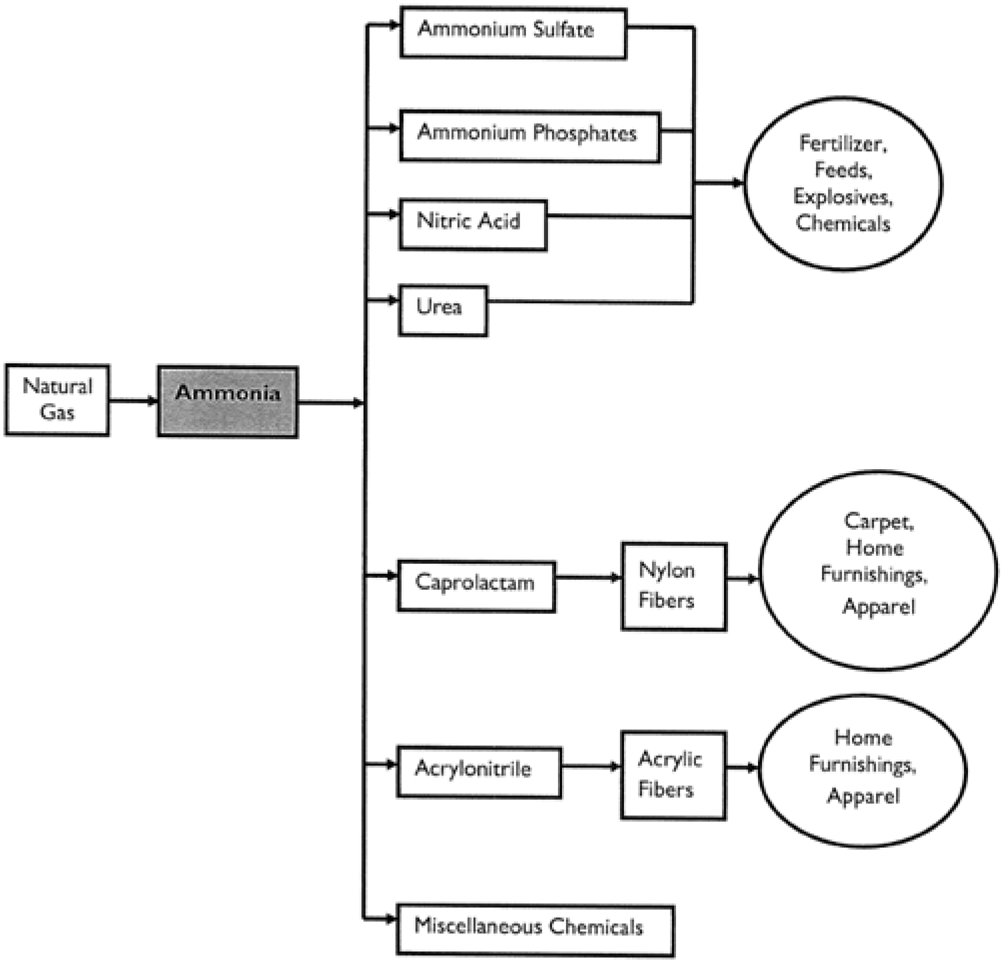


Figure 55: Ammonia chain [ACC, 2013]

Ammonia (NH_3) is the principal source of nearly all synthetic nitrogen fertilisers (Figure 55). Nitrogen fertilisers account for more than 80 % of the world ammonia market [IHS, 2014a]. About 48 % of global ammonia production is used in the production of urea, the most commonly used nitrogen fertiliser, 11 % in the production of ammonium nitrate, 20 % in the production of other fertilisers and 3 % is used directly as fertiliser. The remaining percentage is consumed in uses that include the synthesis of chemicals, explosives, fibres and plastics, refrigeration and others [CEPS, 2014].

After the 7.6 % contraction in 2008/2009, world fertiliser consumption sharply rebounded the following two years with growth rates of 5-6 %, reaching 107.5 Mt_N in 2011/2012 [IFA, 2011; IFA 2012], but since then the market has been stabilised. Consumption for 2012/2013 was 108.8 Mt_N, and in 2013/2014 it is estimated to reach 112.2 Mt_N [IFA, 2013; IFA 2014]. In recent years the rising prices of natural gas and oil in certain geographical areas resulted in the increase of the price of ammonia. This was most noticeable in 2008. As a result, capacity has increased in areas where natural gas is cheaper, especially in the United States, with the exception of China were coal is used as the main feedstock.

Figure 56 shows the world distribution of ammonia consumption in 2013.

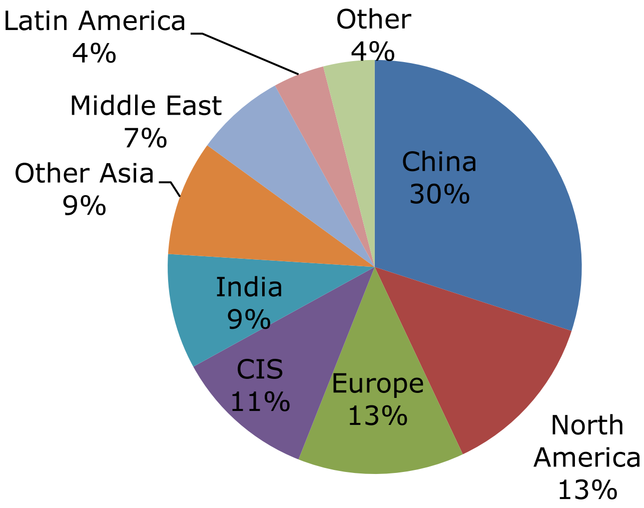


Figure 56: World ammonia consumption by region in 2013 [US SEC, 2014]

World ammonia production in 2012 was 198 Mt_{NH3} according to the International Energy Agency [IEA, 2013] and 180 Mt_{NH3} according to a US Geological Survey [USGS, 2014] with the EU, Russia, Saudi Arabia, Ukraine and the United States covering about 27 % of world production [USGS, 2014]. The world ammonia capacity was 204.1 Mt_{NH3} in 2012 and about 211 Mt_{NH3} in 2013 [IFA, 2013; IFA 2014]. This latest estimation is in accordance with the reported world installed capacity of 214 Mt_{NH3} [IHS, 2014b], with the EU covering about 9 % and with all five countries of interest covering 23.5 % [IHS, 2014b]. It is interesting to note that in 2013 the EU and Saudi Arabia had similar load factors (81.6 % and 82.2 % respectively), while Russia had higher load factors and the US lower (87.7 % and 73.5 % respectively) [IHS, 2014b]. China dominates world capacity and production, reaching almost 35 % [USGS, 2014]. Figure 57 shows the evolution of capacity from 2009 to 2013 in the regions of interest, including China for comparison purposes.

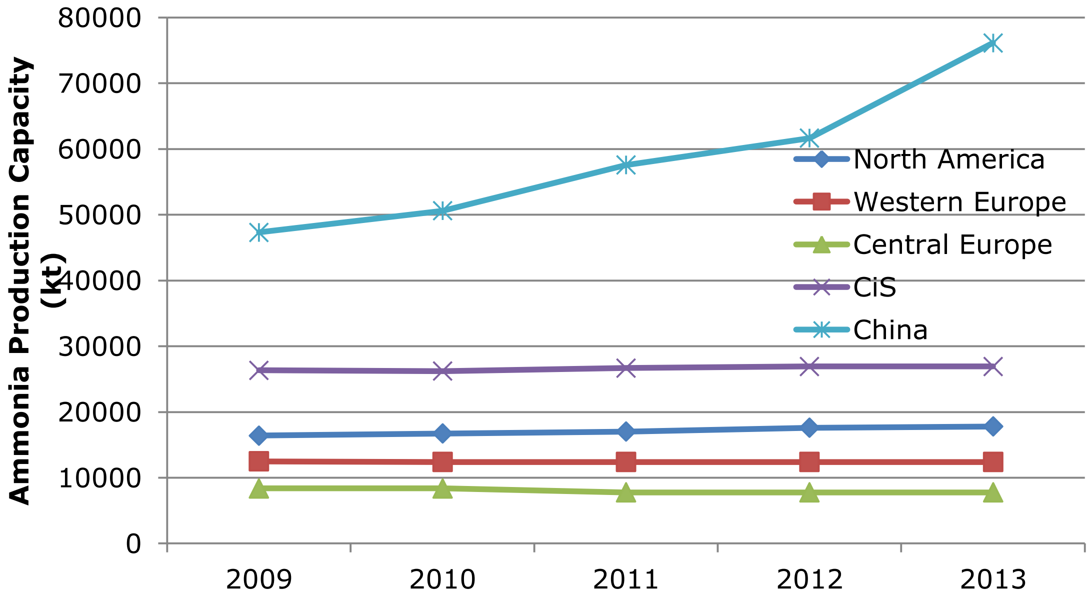


Figure 57: Annual nominal capacity of ammonia plants in different regions for the years 2009-2013 [US SEC, 2014]

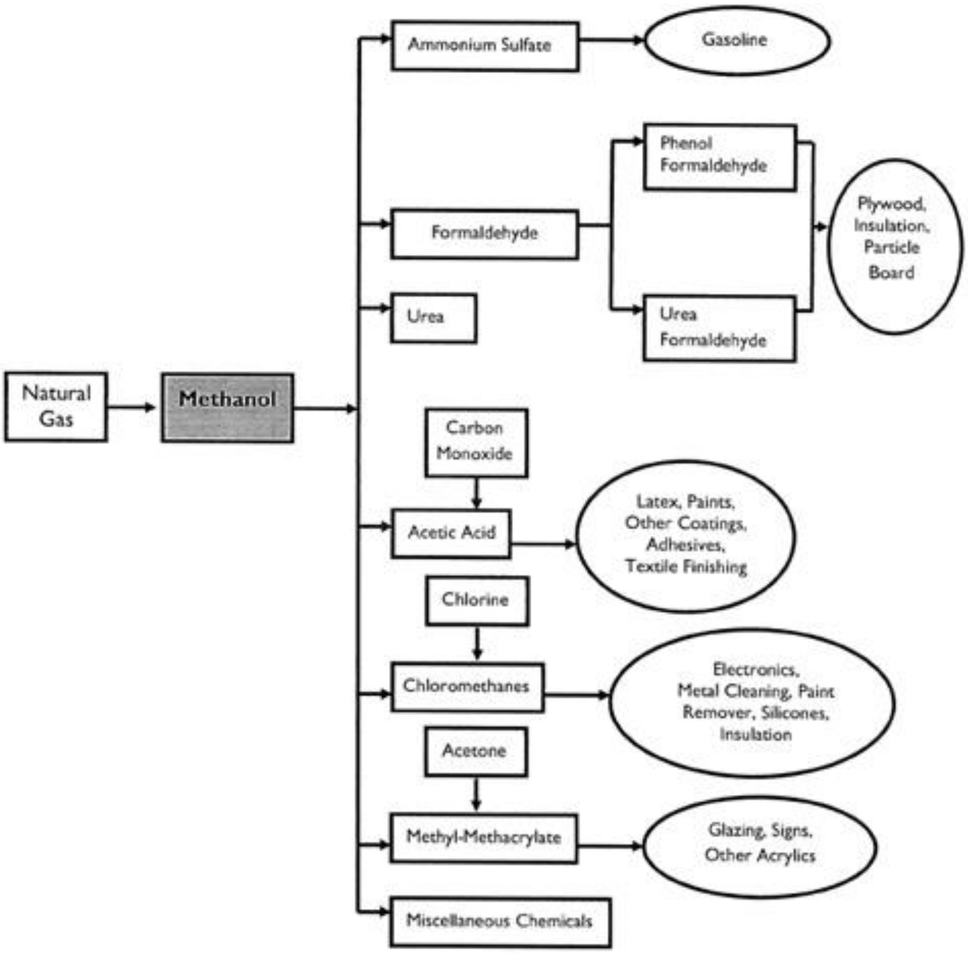


Figure 58: Methanol chain [ACC, 2013]

Methanol (CH_3OH) is the simplest alcohol, also known as methyl alcohol and is used as antifreeze, solvent and fuel. Its derivatives are shown in Figure 58. Formaldehyde is the main derivative of methanol accounting for 31 % of the world methanol demand in 2012 [MMSA, 2013] and 2013 [IHS, 2014c]. The use of methanol in direct fuel applications includes methyl tert-butyl ether (MTBE)/tert-Amyl methyl ether (TAME), biodiesel, gasoline blending and dimethyl ether (DME), accounting in total for 37 % of the world methanol demand [MMSA, 2013]. Figure 59 shows world consumption of methanol, by end use.

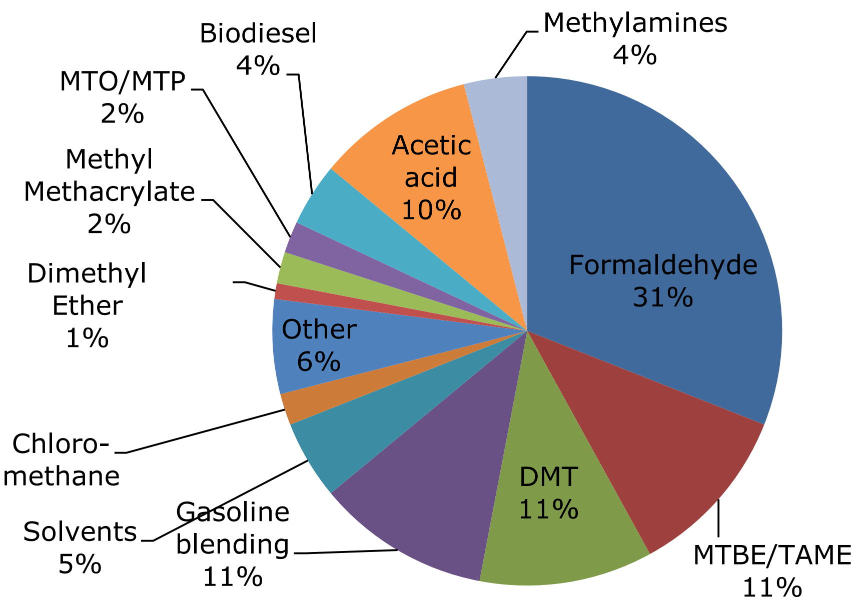


Figure 59: World consumption of methanol by end use (2013) [IGP Energy, 2015]

Global methanol production in 2012 was 58 Mt according to the International Energy Agency [IEA, 2013] or 60.6 Mt according to Methanol Market Services Asia [MMSA, 2013]. None of the top ten companies, operating 27 % of world methanol capacity, are located in the EU. They operate mainly in the Middle East and in northeast Asia. China is expected to be the main region of growth of methanol capacities, followed by North America, while in Europe the capacities are expected to remain stable [Berggren, 2013].

The nameplate capacity installed worldwide in 2012 was 95.5 Mt [MMSA, 2013], while in 2013 it increased to 98.3 Mt, with the EU accounting for about 3 %, mostly located in Germany, while Saudi Arabia covers 7.4 % [IHS, 2014b]. During recent years the EU industry has gone through changes. A plant in Germany was converted to produce exclusively ammonia in 2008, while a company in the Netherlands left the methanol business in 2006 due to high gas prices. For the same reason, another plant located in Romania stopped its production in 2013. The countries of interest to this study reach a total coverage of 15.9 % of world capacity [IHS, 2014b], while China covers about 50 % of the world capacity and consumption [IHS, 2014c].

It is also interesting to note that in 2013 the EU had load factors of about 81.5 %, similar to Saudi Arabia, while Ukraine and the United States had operating rates of around 74 % and Russia around 88 % [IHS, 2014b]. Concerning the United States, due to an increase of the nominal capacity of approximately 500 Mt between 2012 and 2013, the load factor decreased from 85 % in 2011 and 2012 to 74 % in 2013. However, thanks to the shale gas revolution and the new investments, production is expected to increase in the next five years.

Total methanol production in the EU was about 2.5 Mt, while total consumption in western Europe ([11]) reached 6.6 Mt, 700 kt less than in 2008, and in central Europe ([12]) 1.0 Mt. The gap of methanol demand is covered by imports: in western Europe mainly from Egypt, Russia and Saudi Arabia and in central Europe mainly from Russia and western Europe. The United States produced 1.2 Mt methanol in 2013 and consumed

([11]) Western Europe usually includes the members of EU-15, but in this case also Norway, where a plant with a nominal capacity of 900 kt is located [Statoil, 2014].
([12]) Central Europe, in some databases also referred to as central and eastern Europe, usually includes Bulgaria, Croatia, the Czech Republic, Hungary, Montenegro, Poland, Romania, Serbia and Slovakia.

almost 6.5 Mt, with imports of almost 5.4 Mt coming mainly from Trinidad and Tobago and Venezuela. By contrast with the EU and the United States, Russia and Saudi Arabia are net exporters of methanol. The largest methanol producing country in the world is China, but its total production does not cover its demand, and as a result, it has become the largest importing country in the world.

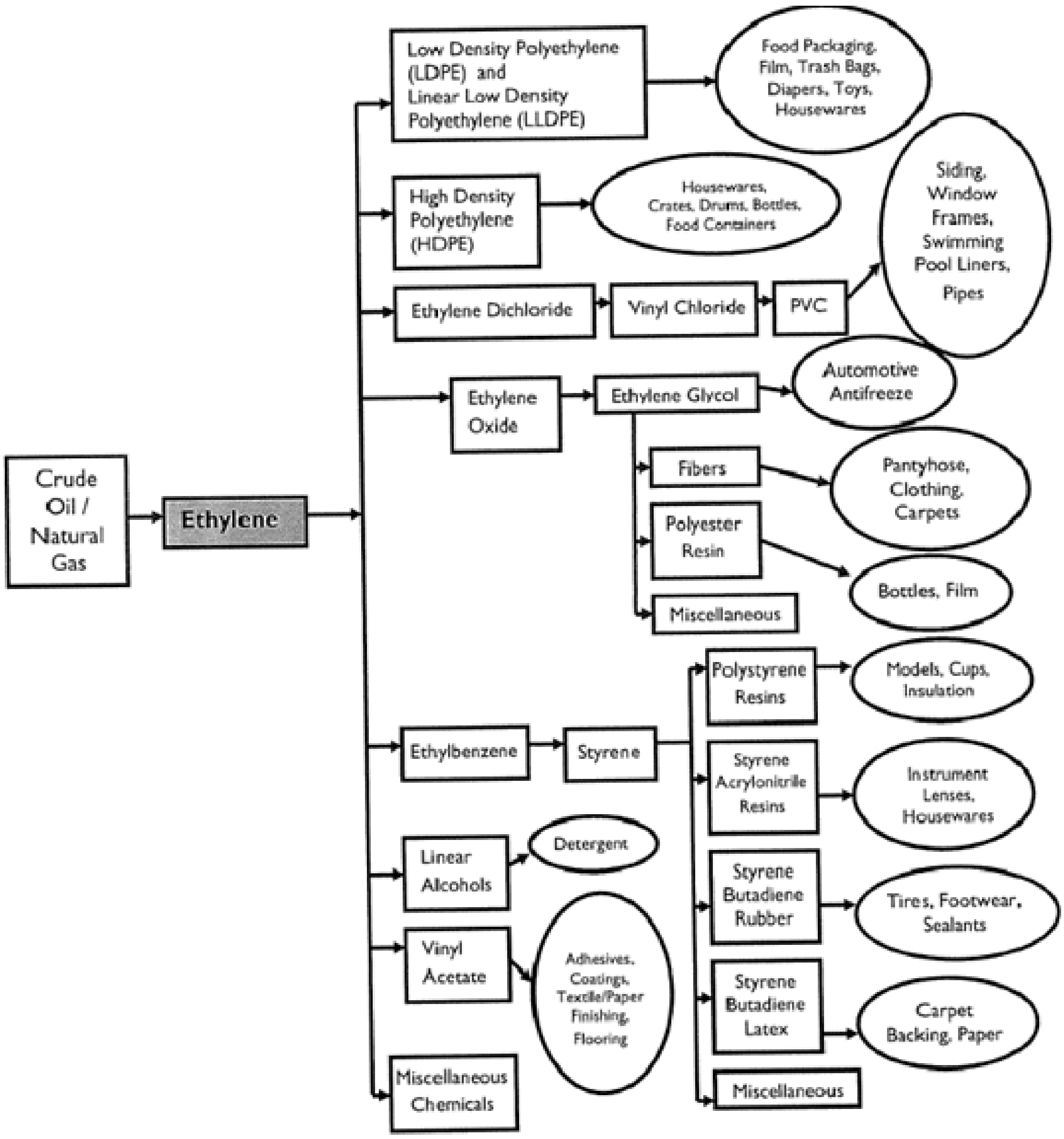


Figure 60: Ethylene chain [ACC, 2013]

Ethylene or ethene (C_2H_4) is one of the largest-volume chemicals worldwide and is used as raw material in the production of plastics, fibres and other organic chemicals. It is the basic chemical for about 30 % of all petrochemicals [Ecofys, 2009]. An overview of its derivatives is shown in Figure 60. The first main derivative of ethylene is polyethylene, with markets in film, packaging and products for home and light industrial use. The second one is ethylene oxide, used mainly to produce ethylene glycol and finally PET bottles. Both derivatives account for over 60 % and 15 % of the total use of ethylene, respectively [IHS, 2014d]. In western Europe ([13]) 60 % of ethylene is used for the

([13]) For Petrochemicals Europe western Europe is EU-15 and Norway.

production of polyethylene of different types, while ethylene dichloride is the second main derivative (15 %) [Petrochemicals, 2014].

The ten largest ethylene producers in the world account for about 46 % of world capacity. They operate all over the world, distributed mainly in North America, the Middle East, northeast Asia and Europe [OGJ, 2014].

Global ethylene consumption reached 129 Mt in 2012 [Eramo, 2013] and 133 Mt in 2013 [IHS, 2014b]. Since 2009, the average annual growth rate of ethylene consumption has been almost 4.5 % [IHS, 2014d], and the global capacity has reached 154.4 Mt in 2013, meaning an annual increase in the capacity of 2.3 %. The EU accounted for 16.3 %, the United States for 17.8 % and Saudi Arabia for 10.2 % [IHS, 2014b] of the installed capacity in 2013. When including all the countries within the scope of this study, a coverage of 46.7 % is reached [IHS, 2014b]. In western Europe ethylene capacity decreased in 2012 to 23.8 Mt, with production reaching 19.0 Mt [Petrochemicals, 2014]. Ethylene production in the same year in the United States was 24.0 Mt [ACC, 2013]. The main ethylene producer in 2013 in the world was the United States, with 19.6 %, while China covers about 9.6 % and Saudi Arabia 9.1 % of the capacity [OGJ, 2014]. Shale gas and unconventional oil have caused an increase in the investments in hydrocarbon production in North America, and the Middle East is seeking domestic supply options along with exports. On the other hand, China is strengthening domestic investments and reducing import dependencies [Eramo, 2013].

Saudi Arabia and the United States had the highest load factors in 2013 (over 90 %), while Russia and western Europe had operating rates of around 79 % and Ukraine the lowest of all countries of interest (57 %). Central Europe had load factors between 73.3 % and 81.2 %, with the Czech Republic and Slovakia in the lowest range and Hungary in the highest [IHS, 2014b].

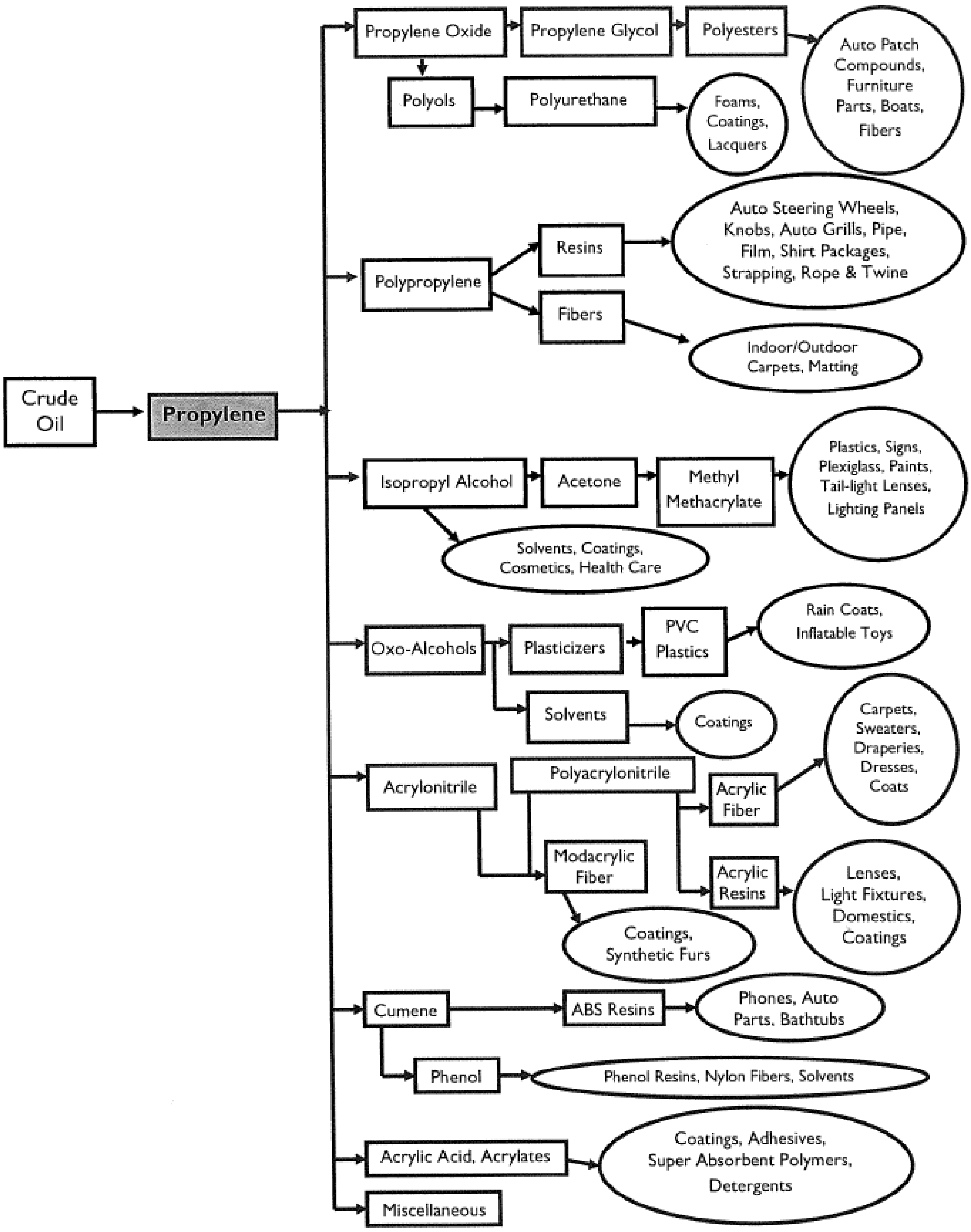
Western Europe is a net importer of both ethylene monomer and derivatives coming mainly from North America and the Middle East. Its exports for 2014 are expected to reach 0.15 Mt, with central Europe ([14]) as the main destination. The latter is also a net importer, with the Middle East as the largest supplier [IHS, 2014b]. Russia, on the other hand, is a small net exporter of ethylene monomer, which can be attributed mainly to the volume delivered to Hungary along a pipeline, but it is a net importer of derivatives. The Middle East enjoys the lowest-cost ethylene feedstock in the world and therefore the derivatives from this region compete with and displace products around the world, especially since they also benefit from favourable shipping logistics to large customers in southeast and northeast Asia and India.

Propylene or propene (C_3H_6) has similar uses to ethylene and its derivatives are illustrated in Figure 61. Polypropylene is the principal driver of propylene demand. It accounts for 65 % of the total global use of propylene [CIEC, 2013], however, this percentage varies per region, from 53 % in North America to more than 90 % in the Middle East in 2010 [IHS, 2011a]. In western Europe in 2013, 56 % of propylene was used in the production of polypropylene and 13 % for propylene oxide [Petrochemicals, 2014].

Most of the world’s propylene production and consumption has historically been concentrated in North America and western Europe, representing 38 % of total production in 2010. Propylene is sold in three different quality grades: refinery (55-75 %), chemical (92-96 %) and polymer (>99.5 %). Refinery-grade (RF) propylene results from the refinery catalytic cracking (FCC) process, while propylene obtained from steam cracking is at least chemical-grade (CG) purity up to polymer grade (PG).

([14]) Central Europe in this case includes Bulgaria, Czech Republic, Hungary, Poland, Romania, Slovakia and the countries of former Yugoslavia (Bosnia and Herzegovina, Croatia, the former Yugoslav Republic of Macedonia, Montenegro, Serbia and Slovenia).

Figure 61: Propylene chain [ACC, 2013]



The global propylene demand in 2012 was 88 Mt and the total capacity was estimated to be 100.4 Mt [Pandia, 2014]. In 2013 the installed nameplate propylene capacity was 105.7 Mt for polymer/chemical grade and 45 Mt for refinery grade [IHS, 2014b]. The EU accounts for 17.3 % of the polymer/chemical-grade capacity, having an equal share with the United States, and for 11.4 % of the refinery-grade capacity. The coverage of the capacity of all the countries within the scope of this study is 43.6 % and 39.3 % for the two grades, RF and CG/PG, respectively [IHS, 2014b]. The load factors of western Europe, Russia and Saudi Arabia are similar in the case of propylene chemical/polymer grade (CG/PG) (around 82 %), while Ukraine and the United States are operating at rates around 65 % and central Europe at rates between 70 and 80 %, with the only exception being Bulgaria that is operating at full rate [IHS, 2014b]. In the case of propylene refinery grade (RF), all regions operate with load factors between 70 and 80 %, with the only exception being Bulgaria and Russia, who operate at full rate [IHS, 2014b].

C.4 Research protocol

This document follows a bottom-up approach to assess the different costs of the manufacturing processes, based on the information at facility level provided by IHS Chemical in the form of a database [IHS, 2014b]. The facilities covered in this study fall within the classes 20.13 and 20.14 of the NACE Rev. 2 classification. They both include the manufacture of chemicals using basic processes, with the difference that 20.13 refers to inorganic, while 20.14 refers to organic compounds [EC, 2008].

This study provides an analysis using as basis year the one with the most recent information available at the time of writing, which is 2013. The database provided by IHS Chemical covers all facilities in the countries of interest that produce the four products. Table 28 shows the number of facilities included in the database, and therefore in this study.

Table 28: Number of facilities per chemical product included in the analysis

	Ammonia	Methanol	Ethylene (15)	Propylene		
				Refinery grade	Chemical/polymer grade	
					All	Without steam crackers
EU	48	5	50	50	91	43
Russia	28	10	14	4	16	6
Saudi Arabia	6	8	15	1	20	7
Ukraine	9	1	2	-	1	-
United States	25	5	41	75	72	38
Total	116	29	122	130	200	94

In the database some information depends on facility, process or country. For each facility the nominal capacity, as well as the process used, is known. The operating rate and all the prices depend on the country in which the facility is located. Lastly, consumption, production and operators needed depend on the process used by each facility.

The different products will be presented separately, and the analysis, although similar in general, is adjusted to the individual characteristics of each product.

For **ammonia** and **methanol** there is only feedstock and electricity consumption included in the analysis, without separating any thermal needs of the process. Methanol is an exothermic reaction, and in ammonia feedstock consumption covers both energy and non-energy requirements.

For **ethylene**, as explained before, steam cracking produces several co-products including ethylene and propylene. As previously mentioned, there are different ways to express consumption and costs, depending on what is considered as final product. In this study the analysis for the same plants will be done following two approaches: one

(15) Besides ethylene, these plants are also producing other co-products, including propylene in most cases.

regarding the ethylene as the only main product produced, and a second approach regarding both ethylene and propylene as main products.

For **propylene**, the analysis is also adjusted to the characteristics of the market. Firstly, all the facilities producing propylene are compared for the different countries, including the quantities from steam cracking, which are plants already included in the list for ethylene. But due to the differences in quality of the different grades, the analysis distinguishes between two cases, the refinery grade and the polymer and chemical grade together.

C.5 Components of cost

The breakdown followed in this study generally includes six cost components:

(a) feedstock
(b) credits (due to the value of the co-products)
(c) electricity
(d) thermal energy
(e) other materials
(f) labour and other costs.

The feedstock costs include the cost of the fossil fuels transformed in each process into products (and co-products). As mentioned before, processes like steam cracking are producing a range of products. In the case of valuable co-products, these are taken into consideration as credits, which are deducted from the other costs. The prices for the different feedstocks and products are provided by IHS Chemical, based on major market prices and understanding of the individual markets and representing large industrial consumers [IHS, 2014b]. In particular for natural gas, the prices provided for the EU are compared with data provided by Eurostat [Eurostat, 2014b]. In most cases the facilities producing the chemicals of interest in this study are large consumers corresponding to Band I6 (consumption > $4x10^6$ GJ). For this band only Belgium, Germany, Spain, Italy, Hungary and Romania report prices, and the prices provided by IHS are in accordance with Eurostat data. Due to the restricted data available in Eurostat, if this dataset was used, the price for the rest of the countries would have to be calculated as a weighted average of the prices of the countries reporting. Nevertheless, in the case of ammonia, these countries cover less than 50 % of total production in the EU. As a result, in this particular case, the information provided by IHS is considered more complete than the Eurostat data. In the case of methanol, Germany is the main producer in the EU, but for reasons of consistency in our study, we use the information from IHS. The prices for the rest of the countries have been verified, for Saudi Arabia according to [EIA, 2014], for Ukraine according to [IEA, 2012] and for Russia according to [Euractiv, 2012], and have been found to be comparable.

Concerning electricity prices, the values provided by IHS were used in all countries, except in the EU, where the prices reported by Eurostat have been applied [Eurostat, 2014c]. Eurostat provides more detailed information per country and consumption band than IHS, and therefore is the preferred option. The prices for Saudi Arabia have been verified by comparison with the prices reported by the Saudi Electric Company [SEC, 2014].

Thermal energy costs, when present, refer to fuel required to support the process. External supplies needed are taken into consideration as a general fuel utility, and consumption levels and prices are provided by IHS Chemical based on the detailed analysis of each process. Although included in the thermal energy heading, this value includes capital costs, labour requirements and other costs for this fuel utility. If the process uses steam, this consumption and its cost are reported separately, but aggregated with thermal energy costs.

Most processes also require use of catalysts or other chemicals. These together with water consumed, either for cooling or in the process, are included in the 'other materials' cost component. The prices for these additional utilities are also included in the database provided by IHS Chemical [IHS, 2014b]. Independently of the country, the prices for the catalysts and other chemicals depend only on the process.

'Labour and other costs' includes salaries, overheads both direct (e.g. other employee benefits) and indirect (support functions), property taxes and insurances, as well as labour and materials concerning maintenance. Labour is a function of the number of operators per shift required for each process, the productivity of the country and the hourly rates. Unlike the number of operators that depends on the process and size of the plant, the hourly rates only depend on the facility's location, therefore on the country. The productivity factor, linked to the efficiency, is country and product dependent. All this information is provided by IHS Chemical [IHS, 2014b] and is consistent with the general guidelines provided by *Perry's Chemical Engineering Handbook* [Perry, 2008]. The direct and indirect overheads are expressed as a percentage of the labour, while the property taxes, insurances and the maintenance costs are expressed as a percentage of the total fixed investment (TFI). The TFI for each facility is calculated based on a reference facility, which depends on the technology used, and according to the following equation [Perry, 2008]:

Cost of facility i = Cost of reference facility (capacity of facility i/capacity of reference facility)$^{0.7}$

Table 29: Prices of feedstocks, co-products, utilities and labour in the chemical industry in 2013

		Units	Russia	Saudi Arabia	Ukraine	United States	EU (16)
Feedstocks	Natural gas	EUR/t	114.10	29.70	425.42	148.96	442.99
	n-Butane	EUR/t	546.01	475.40	564.83	470.39	638.80
	Ethane	EUR/t	296.54	46.28	549.67	145.96	612.44
	Distillate fuel oil	EUR/t	620.65	698.50	620.65	667.46	698.12
	Naphtha	EUR/t	564.64	708.56	613.42	669.58	671.67
	Propane	EUR/t	549.61	480.49	560.91	394.34	612.16
	Refinery gas	EUR/t	391.92	111.96	488.66	244.57	409.74
Co-products	C1 fuel	EUR/t	182.58	49.51	304.56	143.46	525.86
	C3s crude	EUR/t	831.80	495.78	962.37	966.37	1 007.55
	C4s crude	EUR/t	468.99	720.01	786.02	835.58	885.02
	Residual fuel oil	EUR/t	217.71	454.99	426.96	474.60	468.42
	Hydrogen	EUR/t	466.47	126.48	778.13	366.52	1 343.51
	Pygas	EUR/t	679.45	804.61	743.72	773.89	789.01
Utilities	Electricity	EUR/kWh	0.039	0.024	0.059	0.035	0.085 (17)
	Cooling water	EUR/t	0.014	0.010	0.019	0.013	0.025
	Process water	EUR/t	0.019	0.015	0.025	0.018	0.031
Labour	Hourly rate	EUR/h	4.79	15.09	3.57	20.86	18.01

Table 29 shows the prices used in this study per country for different feedstocks, co-products and the utilities common to all processes, as well as the hourly rates. For the

(16) For the EU only the average of the prices is shown in this table, but in the analysis the prices per country are used (when available) and not an average.

(17) This average refers to Band IE according to Eurostat, but in the actual analysis the price per country and per consumption band for each facility was used.

EU an average of the prices in each country is shown in the table. Nevertheless, in the analysis the individual prices per country were used depending on the geographical position of each facility. It is noteworthy in the case of the hourly rate that, as a whole, the average hourly rate in the EU is lower than the one in the United States, but if the EU is divided into western and eastern Europe, the averages are 23.31 and 5.28 EUR/h respectively. Eastern Europe includes Bulgaria, the Czech Republic, Hungary, Poland, Romania and Slovakia.

C.6 Energy and raw materials consumption

This section provides an overview of total energy consumption per product and process. As already described in Section C.4, we have relied on the values reported in the IHS Chemical database [IHS, 2014b]. However, the performance of the processes has been compared with the information provided in the literature, see Section C.2. The information on energy and materials consumption is used in Section C.7, in combination with the information described in Section C.5, to provide an estimation of the overall energy and materials costs of the industry in the production of each product.

All consumption is expressed as tonne of feedstock, utility or co-product per tonne of main product. The only exception is catalysts and other chemicals, for which the cost per tonne of main product is known. Nevertheless, it is presented in this section because it is allocated to the materials consumed in the process of producing the chemicals. The information in Table 30 to Table 33 is arranged in sections that include feedstocks, co-products (if present), utilities and other materials.

In the case of **ammonia**, the main feedstock used in the countries of interest is natural gas, and as a result the main process is steam reforming. A few facilities in the United States are using coal as feedstock and therefore partial oxidation. Consumptions of the two processes are shown in Table 30.

Table 30: Consumption of the ammonia-producing processes

		Units	Process based on natural gas	Process based on coal
Feedstock	Natural gas	t/t	0.65	
	Coal	t/t		1.39
Utilities	Electricity	kWh/t	80.0	500
	Cooling water	t/t	200	250
	Process water	t/t	0.94	12
Other materials	Catalyst ([18])	EUR/t		5.50
	Chemicals	EUR/t	1.51	2.18

([18]) As explained, for catalysts and chemicals only the cost per tonne of product is known and not actual consumption.

Concerning **methanol**, there are several processes used in the industry of the countries of interest. Table 31 shows consumptions of feedstock, utilities and other materials for these processes.

Table 31: Consumption of the methanol-producing processes

		Units	Steam reforming	Mega Lurgi	Mega Mitsubishi	Mega ICI	Coal process	Heavy liquid process
Feedstock	Coal	t/t					1.99	
	Residual fuel oil	t/t						0.80
	Natural gas	t/t	0.65	0.58	0.58	0.58		
Utilities	Electricity	kWh/t	65.0	25.0	22.5	25.0	450.0	180.0
	Cooling water	t/t	90.0	10.0	9.0	10.0	400.0	90.0
	Process water	t/t	2.0	0.80	1.80	0.80	12.0	0.8
Other materials	Catalyst ([19])	EUR/t	0.75	1.51	1.51	1.51	5.72	
	Chemicals	EUR/t	0.56					

In the case of **steam cracking** for producing ethylene, there are several feedstocks that can be used in the process and most facilities are using mixtures of them. Table 32 shows consumptions of feedstocks, utilities and other materials per process, as well as co-products that derive in each case, when only one feedstock is used. Combined feedstocks are calculated from these consumptions by taking into consideration the percentage of each feedstock in the mixture. The same methodology is followed for co-products, utilities and other materials.

([19]) As explained, for catalysts and chemicals only the cost per tonne of product is known and not the actual consumption.

Table 32: Consumptions of the steam cracking processes

		Units	High-severity naphtha	Distillate fuel oil	Light naphtha	n-Butane	Propane	Ethane	Refinery gas
Feedstock	Naphtha	t/t	3.30						
	Light naphtha	t/t			3.25				
	Distillate fuel oil	t/t		4.67					
	n-Butane	t/t				2.51			
	Propane	t/t					2.38		
	Ethane	t/t						1.29	
	Refinery gas	t/t							2.18
Co-products	C1 fuel ([20])	t/t	0.50	0.48	0.62	0.56	0.65	0.11	0.89
	C3s crude ([21])	t/t						0.04	
	C4s crude ([22])	t/t	0.34	0.43	0.30	0.26	0.10	0.04	0.13
	Residual fuel oil	t/t	0.13	1.15	0.13	0.04	0.1		
	Hydrogen	t/t	0.05	0.05	0.05	0.04	0.05	0.08	
	Propylene	t/t	0.53	0.69	0.53	0.43	0.40		0.14
	Pygas	t/t	0.75	0.88	0.63	0.18	0.16	0.02	0.03
Utilities	Electricity	kWh/t	44	300	250	180	180	140	148
	Cooling water	t/t	400	206	206	206	206	206	206
	Fuel ([23])	t/t	23.5	33	30	26.2	26	22.2	23
Other materials	Catalyst ([24])	EUR/t	5.49	0.72	0.71	0.50	0.51	0.16	0.16
	Chemicals	EUR/t		4.89	4.06	3.92	3.65	3.16	3.16

Finally, Table 33 includes the information about consumption of feedstocks, production of co-products, utilities and other materials concerning propylene produced by ways other than steam cracking.

([20]) It is usually methane-rich gas.
([21]) It is the production fraction that can be further processed to propylene of chemical or polymer grade, in addition to the propylene produced directly from the steam cracking.
([22]) It is the production fraction that will give butadiene after processing.
([23]) This fuel consumption represents additional fuel required to support the process, generally for heat generation.
([24]) As explained, for catalysts and chemicals only the cost per tonne of product is known and not actual consumption.

Table 33: Consumptions of the propylene-producing processes, excluding steam cracking

		Units	FCC ([25])	High-severity FCC ([26])	Chemical-grade splitter	Polymer-grade splitter	Dehydro UOP oleflex ([27])	Metathesis ([28])
Feedstock	Ethylene	t/t						0.34
	Propane	t/t			0.44	0.47	1.20	
	Propylene	t/t			0.95	1.01		
	Raffinate-2 ([29])	t/t						0.92
	Distillate fuel oil	t/t	1.61	5.24				
Co-products	C1 fuel	t/t					0.14	0.002
	C1 + C2 fuel	t/t	0.07	0.35				
	Propane	t/t	0.03	0.21	0.39	0.48		
	Butane mixed	t/t	0.07	0.25				0.25
	Hydrogen	t/t					0.06	
	Distillate fuel oil	t/t	0.18	0.82				
	Residual fuel oil	t/t	0.17	0.24				
	Raffinate-1 ([30])	t/t	0.10	0.65				
utilities	Electricity	kWh/t	1.7	5.8	7.9	7.9	120	88.2
	Cooling water	t/t	10.28	35.1	124.9	124.9	137	60.6
	Fuel ([31])	t/t	0.10	0.44			17.82	0.88
	Inert air	t/t						1.54
	Steam low pressure	t/t						0.98
	Steam medium pressure	t/t	0.08	0.94	0.96	0.96		
	Steam high pressure	t/t	– 0.16	– 0.84				
Other materials	Catalyst ([32])	EUR/t	1.96	11.43	2.48	2.50	9.85	6.25
	Chemicals	EUR/t					2.76	

([25]) FCC is usually producing propylene of refinery grade (RG).
([26]) High-severity (HS) FCC is producing propylene of polymer grade (PG).
([27]) This process is producing propylene of polymer grade (PG).
([28]) This process is producing propylene of polymer grade (PG).
([29]) Raffinate-2 refers to C4 residual, obtained after separation of 1,3-butadiene and isobutylene. It consists of 1-butene and 2-butene and small quantities of butanes and other compounds.
([30]) Raffinate-1 refers to C4 residual after extracting butadiene. It consists of isobutylene, 1-butene and 2-butene and small quantities of butanes and other compounds.
([31]) It represents additional fuel required to support the process, generally for heat generation.
([32]) For catalysts and chemicals only the cost per tonne of product is known and not actual consumption.

C.7 Costs

As already explained, the breakdown of the costs is presented per product and country. In general, each component of the costs combines average consumption for each product and process with prices. The values for consumptions are explained in detail in Table 30 for ammonia, Table 31 for methanol, Table 32 for ethylene and Table 33 for propylene, while the prices are given in Table 29. It is noted that our cost estimation excludes capital cost (depreciation).

7.1 Ammonia

Figure 62 summarises overall average costs for the ammonia industry. For the EU, total average costs in 2013 amounted to 336.8 EUR/t, with 85 % of it being feedstock costs.

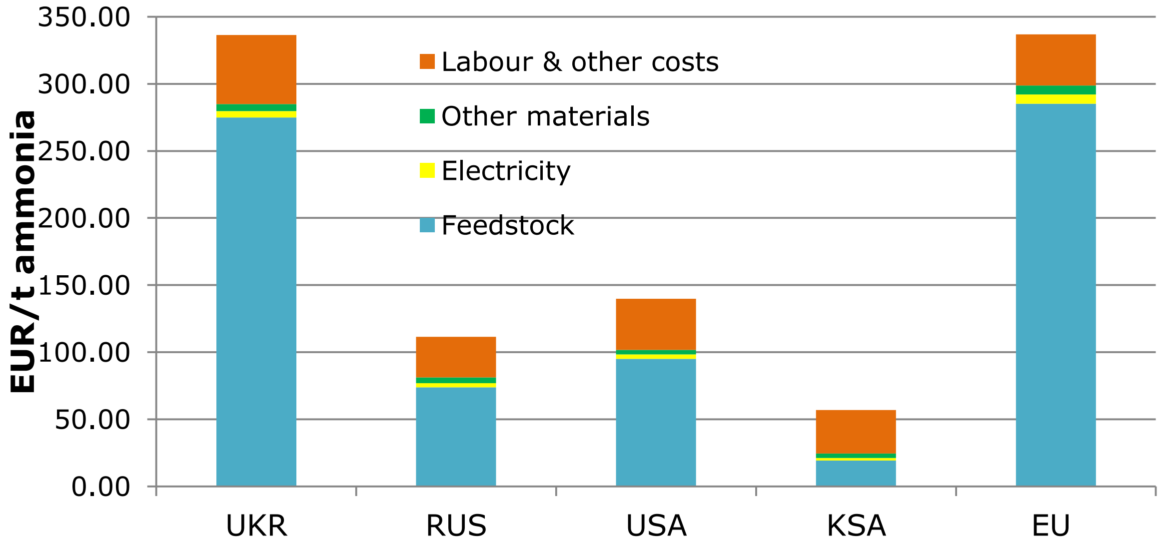


Figure 62: Summary of total ammonia industry costs per tonne of ammonia in 2013

Costs for ammonia production are very dependent upon the cost of feedstock. Since the vast bulk of ammonia is produced from natural gas, the cost of natural gas is the decisive factor determining the ammonia production costs. Natural gas prices vary significantly from region to region, as seen in Table 29. The EU, as well as the other countries, cannot compete with Saudi Arabia, where the natural gas price is around one tenth of the price in the EU.

The only energy cost in the case of ammonia is electricity, but it is not playing an important role. In general, the ammonia industry is a large consumer of natural gas, but only an average consumer of electricity, with most plants in the EU being within bands ID (annual consumption between 2 000 and 20 000 MWh) and IE (annual consumption between 20 000 and 70 000 MWh).

On the other hand, labour and other costs, which include labour overheads, property taxes and maintenance costs, account for 11 % of the overall costs in the case of the EU, for 15 % in the case of Ukraine and 27 % in the case of Russia. Although labour is almost seven times cheaper in Ukraine than in the EU, the productivity of Russia and Ukraine is almost three times lower than in the EU, the United States and Saudi Arabia.

Figure 63 represents the specific costs in each country. In this figure each curve represents a component of the costs and for each one of the curves the countries are ranked according to their increasing average costs. Each vertical line joins the minimum and maximum costs estimated for each country, according to their different performances and prices.

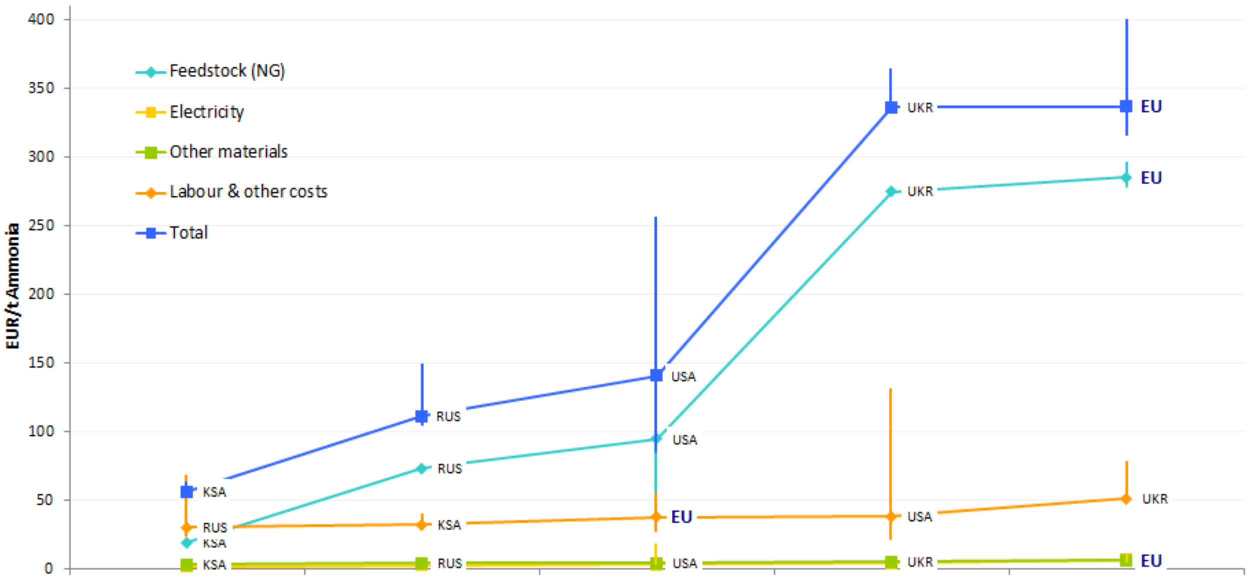


Figure 63: Average cost curves of ammonia production in 2013 and intervals encompassing the maximum and minimum estimated costs

As mentioned before, the differences due to technologies used are few. Only in the United States there are different technologies used; this is depicted in the big difference between the minimum and the maximum costs in the country. Labour is the only component of the costs where there are noticeable variations. These variations are due to the different sizes of the plants, which highly influence the labour and capital costs (the latter affecting the property taxes and the maintenance costs). The EU is in all cases a special case, as it consists of different countries with different prices and productivities.

In this paragraph we provide prices of ammonia in different parts of the world to give an idea of the components of the costs (interest, depreciation of the equipment) and mark-up excluded from this analysis. On the Gulf Coast of the United States the average price of ammonia was about 450 EUR/t [USGS, 2014] and the price in western Europe in April 2013 was reported to be around 350 EUR/t [Market Realist, 2013].

7.2 Methanol

Figure 64 summarises the overall average costs for the methanol industry. For the EU industry the total average costs in 2013 of methanol production was 408.2 EUR/t, of which 85 % was due to the feedstock costs.

As in the case of ammonia, the costs for methanol production are very dependent upon the cost of feedstock. In the countries or regions where the feedstock is locally produced (e.g. in the Middle East and in Russia), production costs are much lower. For this product and in the EU, electricity seems to be a cost component more important than in the case of ammonia, but this is the result of the almost totally localised industry in Germany (90 % of the EU methanol industry is located in Germany). Germany is the second most expensive country for electricity in the EU, after Italy, with the price for band ID being 1.5 times higher than the one in the Netherlands, where the rest of the EU methanol industry is located [Eurostat, 2014c].

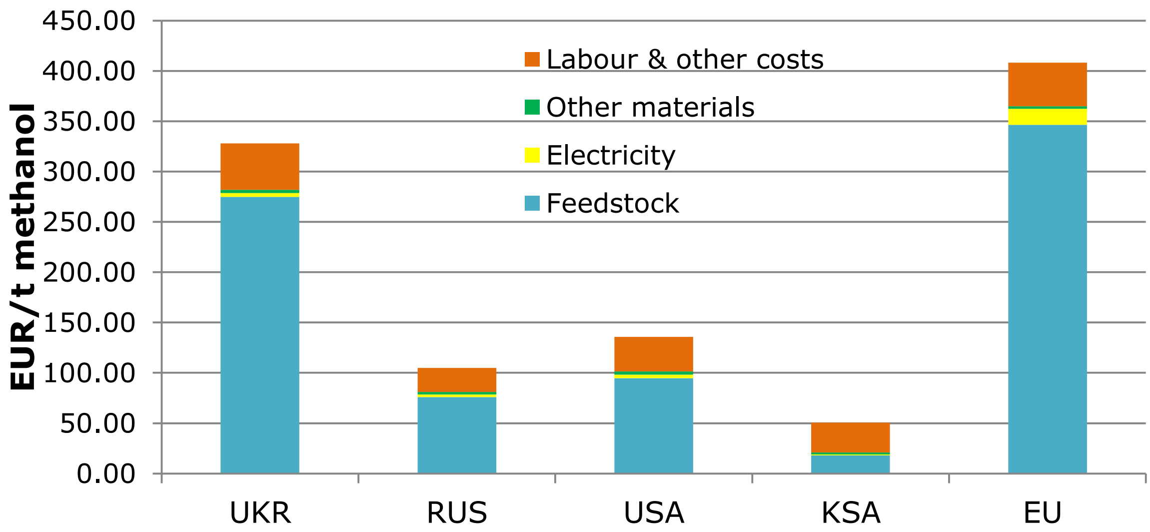


Figure 64: Summary of total methanol industry costs per tonne of methanol in 2013

Figure 65 represents the specific costs in each country. In this figure each curve represents a component of the costs and the countries are ranked according to their increasing average costs. Each vertical line joins the minimum and maximum costs estimated for each country, according to their different performances and prices.

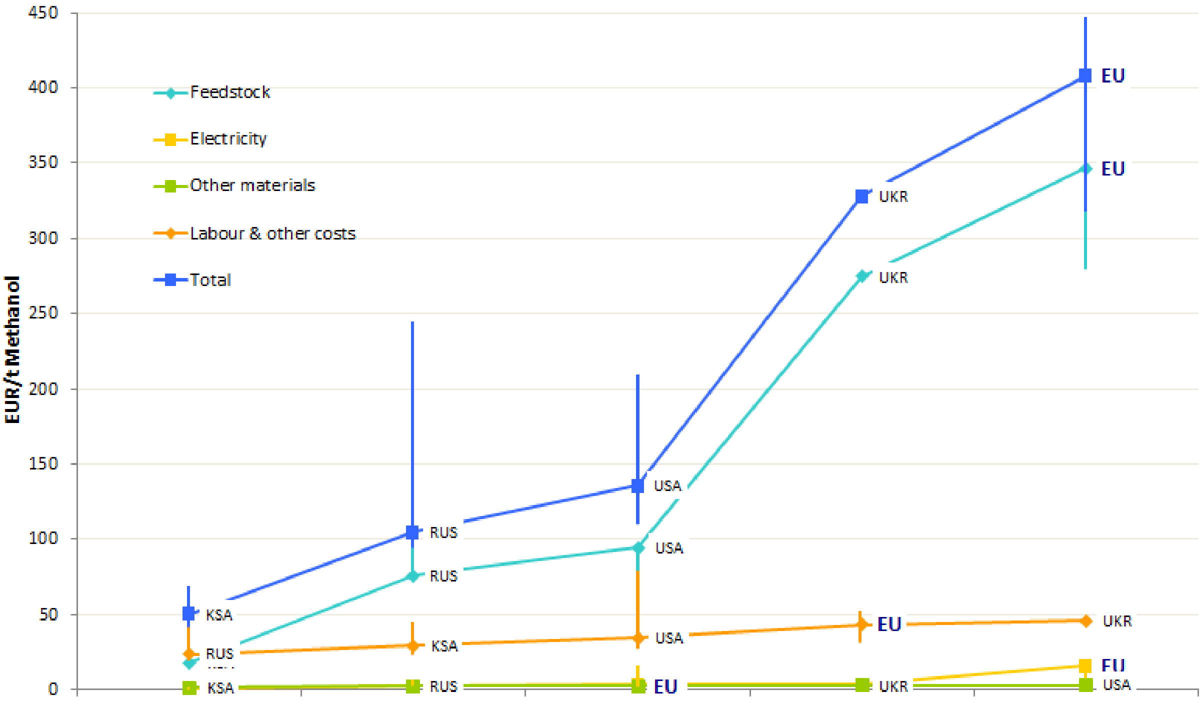


Figure 65: Average cost curves of methanol production in 2013 and intervals encompassing the maximum and minimum estimated costs

In the case of methanol, the minimum and maximum costs are due to both the different technologies and the prices among countries. It is obvious that the feedstock cost is the decisive factor for the total costs, as in the case of ammonia. Although the EU does not have much difference in the costs for the other components, the differences in feedstock costs are noteworthy. The high variability in the total costs in Russia is due to the big difference in the feedstock costs between the processes using natural gas and heavy fuel oil.

As we did for ammonia, we provide the price of methanol here in order to give an idea of the components of the costs and mark-up excluded from this analysis. The price of methanol in Europe during 2013 was in the range 370-450 EUR/t, while in Asia the price ranged between 325 and 414 EUR/t, and the non-discounted reference price was between 362 and 475 EUR/t [Methanex, 2014].

It is obvious from the comparison of costs and prices of methanol, as well as the results shown in Figure 64, that the EU methanol industry is faced with a strong competition. The main change taking place in Europe is the development of biomethanol. There is already a plant in the Netherlands producing methanol, both through the traditional route and through the biogas process. This process allows production of syngas from crude glycerine that is the by-product of biodiesel [Hamm & Voncken, 2013]. A techno-economic analysis of this process has concluded though that currently biomethanol is not competitive with methanol, without the help of subsidies or regulations. Biomethanol can become more attractive if the price of natural gas exceeds 0.45 EUR/Nm^3 or if glycerol is available at less than 90 EUR/t [Balegedde Ramachandran et al., 2013].

7.3 Ethylene

Ethylene, as explained in Section C.2, is produced via steam cracking, but it is not the only product of the process. Therefore, there is an additional component of the costs: the credits due to value of the co-products obtained simultaneously. Figure 66 summarises the overall average costs for the ethylene industry.

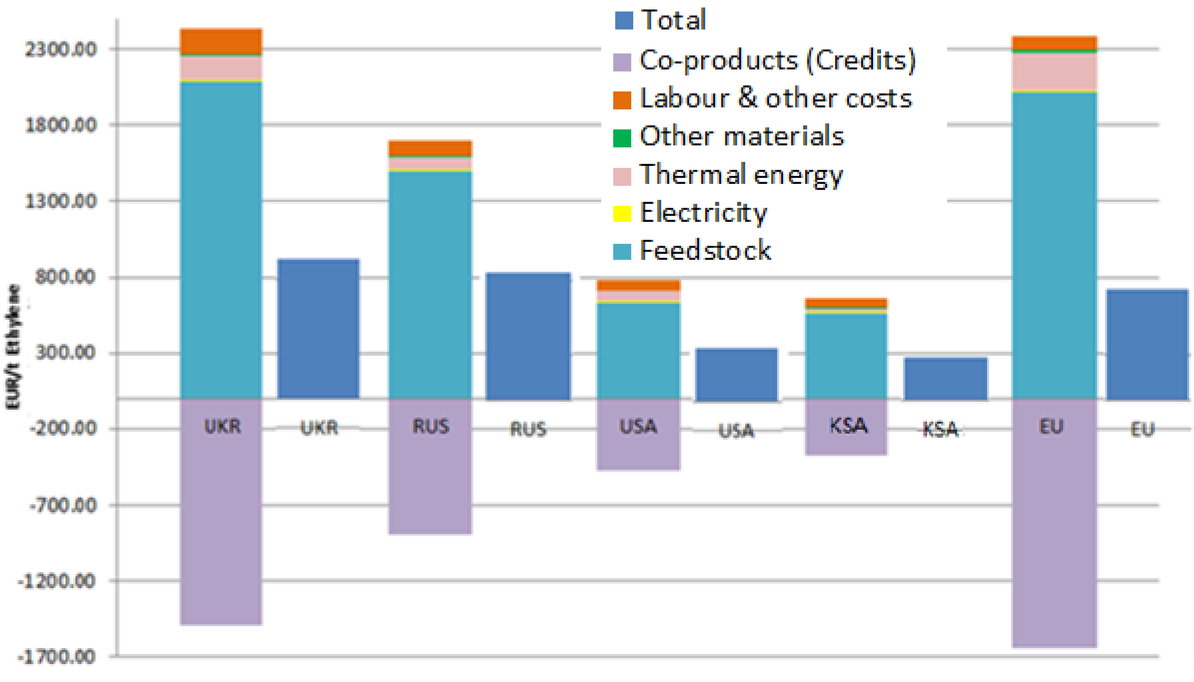


Figure 66: Summary of total steam cracking industry costs per tonne of ethylene in 2013

A major feature of the ethylene industry, and dissimilar to the ammonia and methanol industries, is the variety of feedstocks that can be used in the process. Naphtha has historically been an expensive feedstock in North America, in contrast to domestic natural gas liquids (primarily ethane and propane), and as a result a big part of the American steam cracking industry is based on these latter fuels as feedstock. This is also the case in Saudi Arabia. On the other hand, ethylene producers in the EU and Japan favour petroleum liquid feeds. The choice of feedstock is a decisive factor in the total costs.

Although capital costs are excluded from this analysis, it is worth noting that in ethylene plants, the construction costs depend on the choice of feedstock. Generally ethane feedstock plants cost less to construct than heavier feedstock plants, because the small quantities of co-products generated (see Table 27) do not require expensive recovery equipment. Naphtha and distillate fuel oil-based crackers are 1.5 and 1.7 times more capital intensive than ethane-based plants, respectively.

Although producing more co-products means higher construction costs, it also means bigger credits. As explained for the previous products, the prices of feedstocks in the EU are much higher than in other parts of the world. But if co-products also occur in the process, the value of these co-products is equally affected by those high prices, producing higher credits than in other parts of the world.

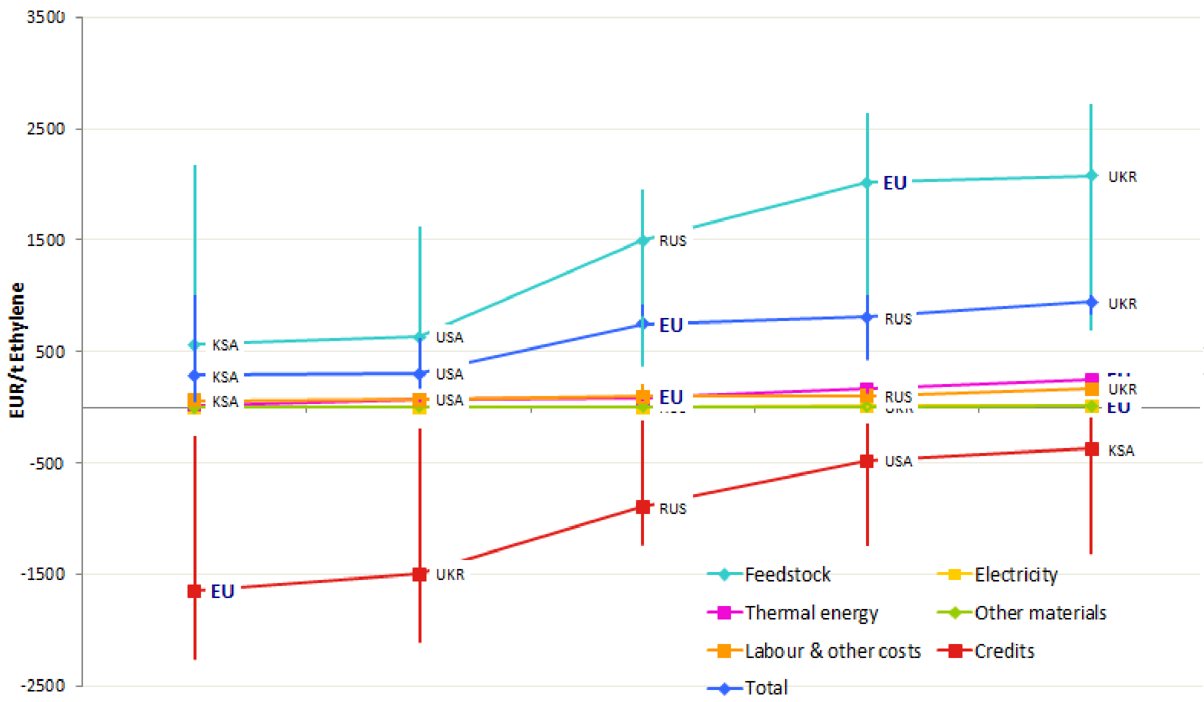


Figure 67: Average cost curves of ethylene production in 2013 and intervals encompassing the maximum and minimum estimated costs

Figure 67 shows the specific costs in each country. The total costs (dark blue curve) for this product are lower than for the feedstock (light blue curve) due to the credits. This industry shows a totally different picture from the ammonia and methanol industries as the EU does not have the highest production costs. The total costs in the EU are lower than in Russia and Ukraine and has smaller variation than Saudi Arabia. The interval defined by the maximum and minimum total ethylene production costs in Saudi Arabia encompasses the variation of total costs in the EU. This happens despite the fact that the natural gas liquids-based industry still has fewer costs than the petroleum liquids-based industry.

As mentioned in Section C.2, consumptions and costs can be expressed in various ways, depending on what is considered as the main product. Figure 66 and Figure 67 are based on considering only ethylene as the main product of the process. If propylene is also considered as main product, though, the costs are then weighted over a tonne of olefins, therefore, propylene is not considered in the credits anymore. It is interesting to note that the price of ethylene in 2013 was 871.7 EUR/t in the United States, 863.2 EUR/t in Saudi Arabia and 1 125.1 EUR/t in the EU, while in the same countries the prices of propylene of chemical grade were 1 060.3 EUR/t, 907.8 EUR/t and 862.6 EUR/t respectively, whereas, for propylene of polymer grade, the prices were 1 086.6 EUR/t, 955.6 EUR/t and 1 035.04 EUR/t respectively [IHS, 2014b]. For Russia and Ukraine there is no information concerning ethylene prices, but propylene could be sold at 700.3 EUR/t or 859.1 EUR/t in Russia, depending on the grade, and at 817.4 EUR/t or 989.9 EUR/t in Ukraine [IHS, 2014b]. The ethane process is producing almost no propylene (Table 27).

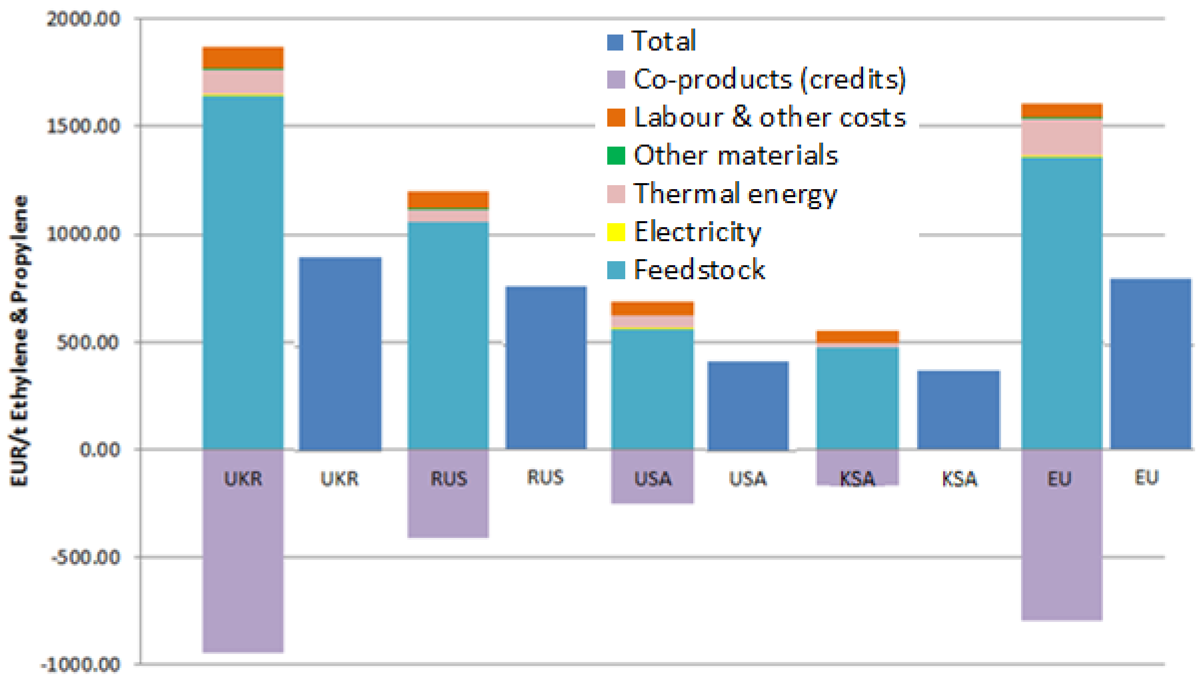


Figure 68: Summary of total steam cracking costs per tonne of olefins in 2013

Figure 68 and Figure 69 summarise the results when considering as main products both ethylene and propylene. As before, the ranking order of each country depends on both the propylene produced and on its price. Since total olefin production is higher than when producing only ethylene, in this case the six components of the costs will be lower than previously, including the credits. In the EU the overall costs amount to 748.4 EUR/t when considering ethylene as only product or 816.2 EUR/t when both olefins are considered as product. Russia and Ukraine also produce higher volumes of propylene than the United States and Saudi Arabia and, when considering the propylene as a product, the total costs of steam cracking are decreased from 809.9 EUR/$t_{ethylene}$ to 782.4 EUR/$t_{olefins}$ in Russia due to the lower price of propylene in these countries.

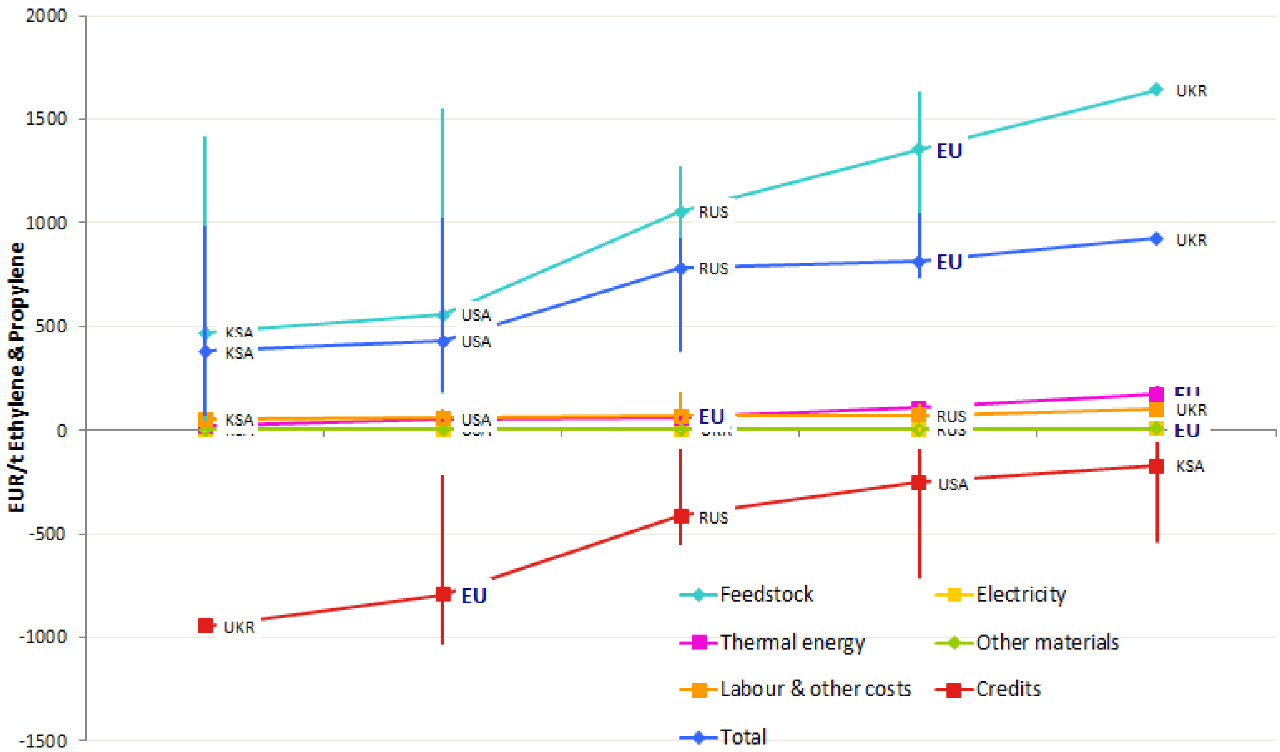


Figure 69: Average cost curves of steam cracking for combined ethylene and propylene production in 2013 and intervals encompassing the maximum and minimum estimated costs

7.4 Propylene

Propylene, as explained in Section C.2, can be produced via several processes. One of them is steam cracking and is already presented in the section on ethylene (Section 7.3). The rest are 'on-purpose' propylene-producing processes. Regardless of the process, the final product is the same and it is undistinguishable in the market. As a result, the costs of all the processes are grouped together (Figure 70 and Figure 71). The only exception can be the refinery-grade propylene that is of lower quality than the chemical- or polymer-grade propylene. As a result, the analysis will distinguish between chemical/polymer-grade propylene (Figure 72 and Figure 73) and only refinery-grade propylene (Figure 74).

Figure 70 summarises the overall average costs for the propylene industry. The differences among the processes are remarkable (Table 33), and in most of the analysed countries propylene is produced by a mixture of all these processes. The only exception is Ukraine, where propylene is produced only via steam cracking. Therefore, the bar corresponding to Ukraine in Figure 70 is exactly the same as in Figure 68. In general, the main factor of the total costs is once again the feedstock, but due to the variety of potential feedstocks, the industries in the different countries are adjusted to the cheapest available feedstock. As a result, there are no remarkable differences in the feedstock costs among the analysed countries.

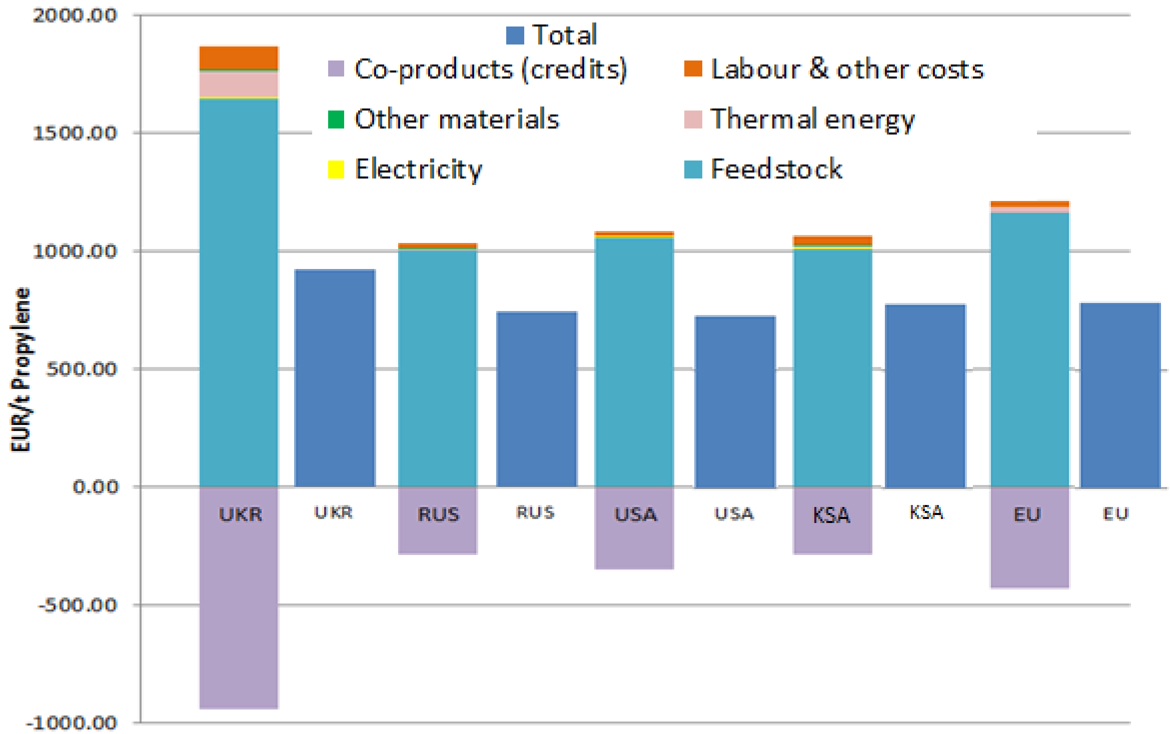


Figure 70: Summary of total propylene industry costs per tonne of propylene in 2013

Figure 71 shows the specific costs in each country. As it can be seen, there are no big differences among the countries, except for Ukraine. The big difference between minimum and maximum costs in Saudi Arabia is worth noting. This is due to the processes used: it is the only country where high-severity fluid catalytic cracking (HS FCC) is being practiced [Parthasarathi & Alabduljabbar, 2014]. This process has higher consumption of feedstock and utilities than the rest of the processes producing propylene.

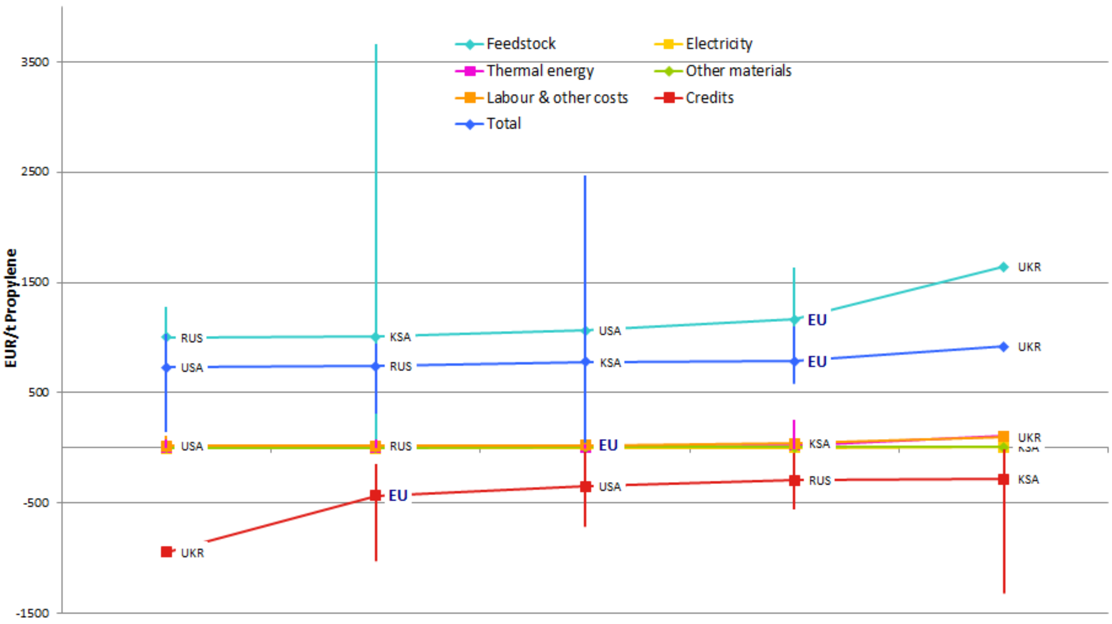


Figure 71: Average cost curves of propylene production in 2013 and intervals encompassing the maximum and minimum estimated costs

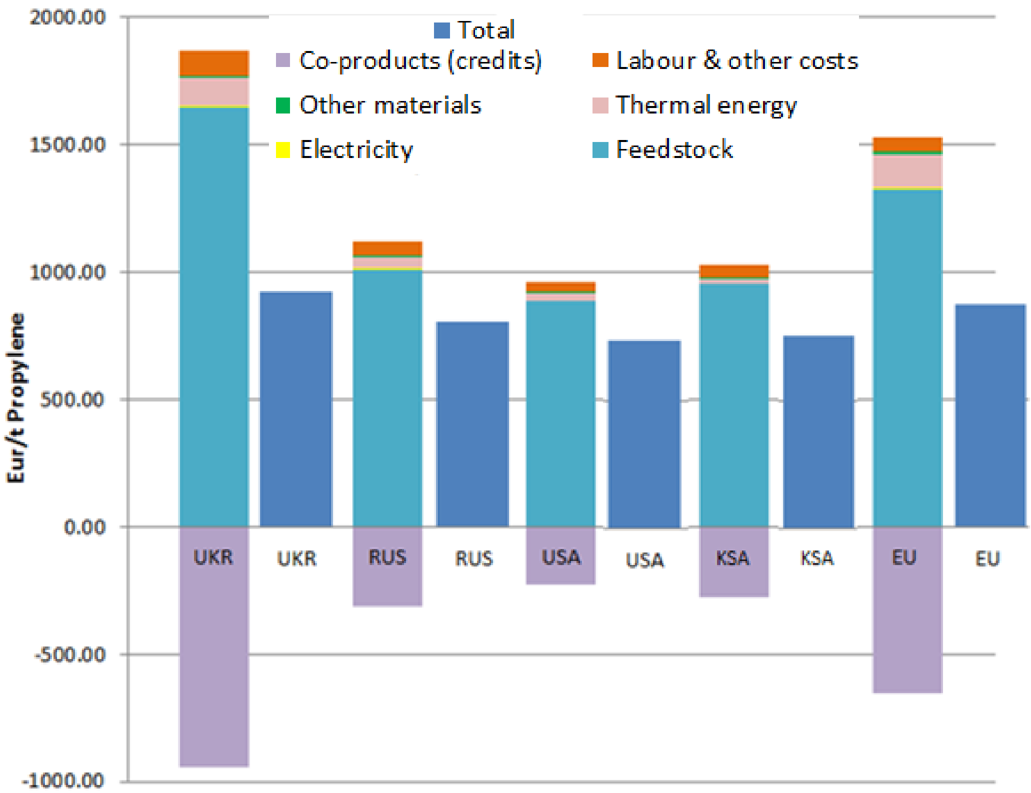


Figure 72: Summary of total production costs per tonne of polymer- or chemical-grade propylene in 2013

The different grades of propylene mean different quality products, especially in the case of refinery grade, compared to the polymer and chemical grades. Therefore, the results for propylene will also be presented for each grade separately. Figure 72 and Figure 73 summarise the results for polymer- or chemical-grade propylene, while Figure 74 is the result for refinery-grade propylene. The average cost-curves graph is not produced for chemical-grade propylene, as the only process by which it is produced is FCC and there are no remarkable differences among the countries, as seen in Figure 74.

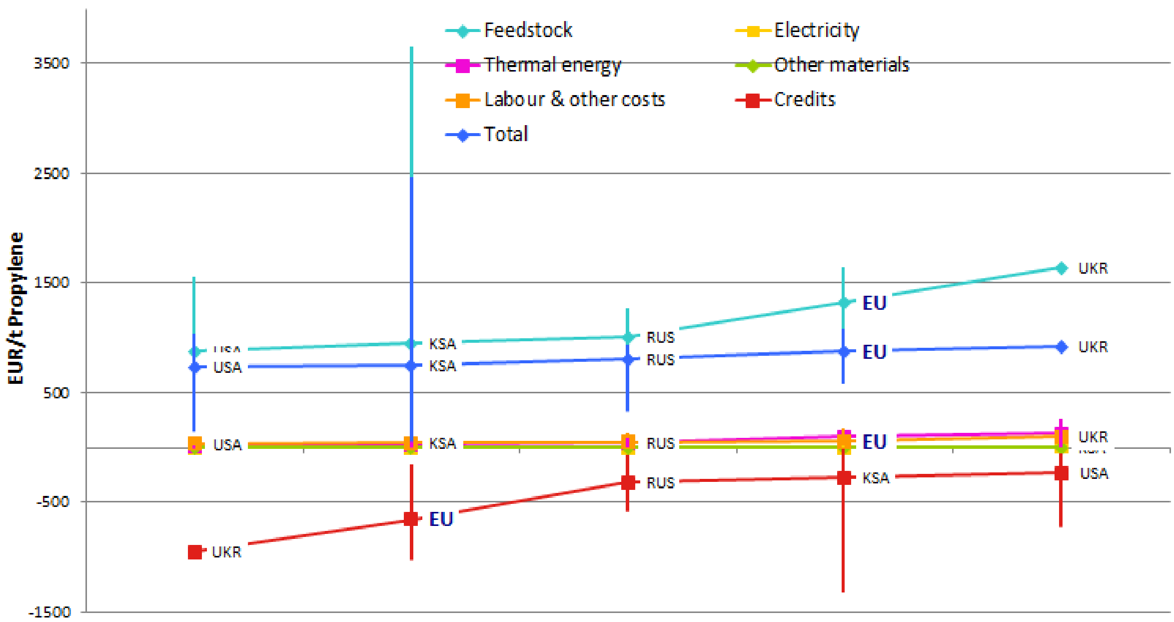


Figure 73: Average cost curves of polymer- or chemical-grade propylene production in 2013 and intervals encompassing the maximum and minimum estimated costs

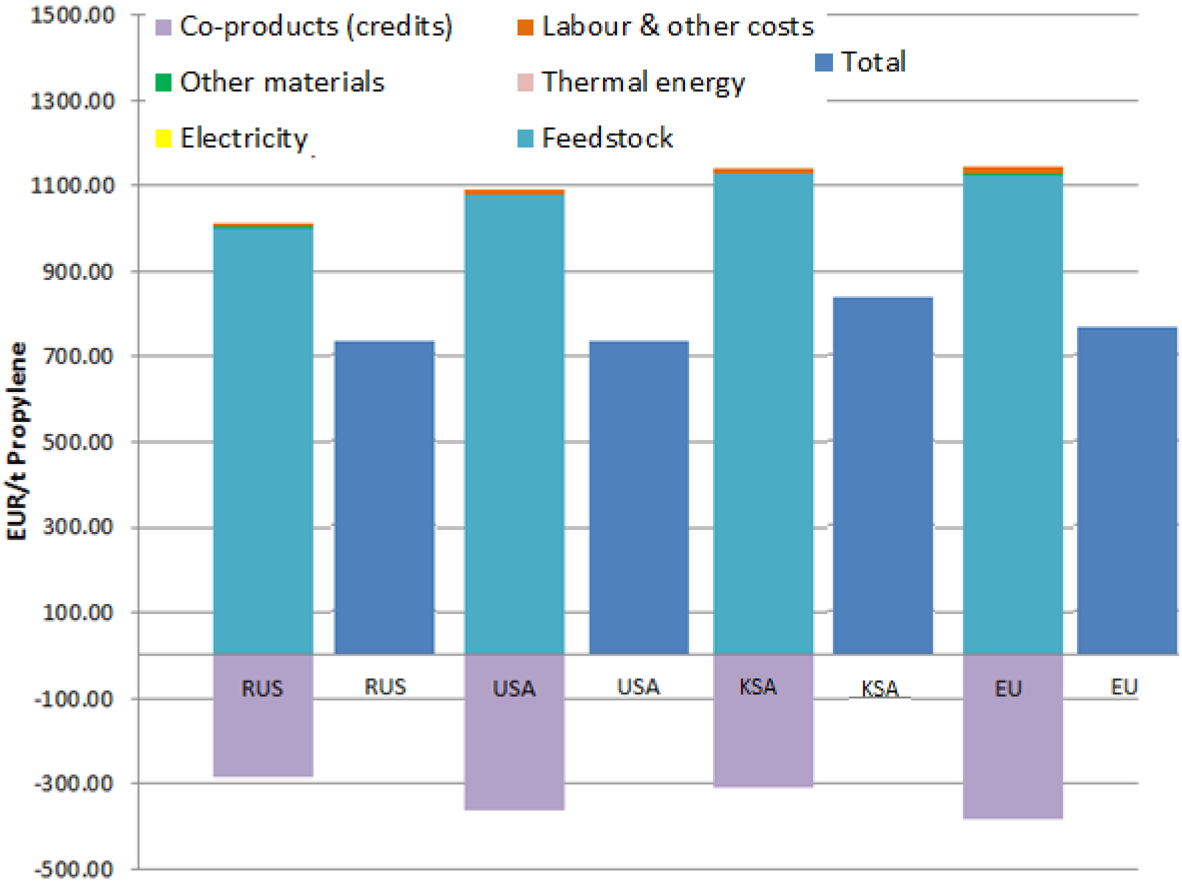


Figure 74: Summary of total production costs per tonne of refinery-grade propylene in 2013

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ANNEX D. Production costs from the non-ferrous metals industry in the EU and in third countries

D.1 Introduction

The purpose of this annex is to provide the results of a combined research and data collection exercise, using public and, where possible, commercial and industry data, aiming to establish different parameters that affect the cost and production process of the non-ferrous metal industry.

The availability and accuracy of information has been a key factor determining the final list of countries included in the collection of data. A first tentative list included China, Kazakhstan, Russia, Saudi Arabia (or Qatar) and the EU as a whole. The fourth section of this document details the final list of countries and the reasons behind the changes. In addition, due to the large number of non-ferrous metals, it was agreed to limit this study to three metals with the highest level of production in Europe: aluminium, copper and zinc.

The second and third sections of this annex are devoted to describing manufacturing processes and provide a glimpse of the market status, whereas the fourth section details the research protocol followed in this report. The fifth section contains the prices of energy and raw materials used, and the sixth section provides consumption of energy and raw materials. All this information is combined in the seventh section to produce an estimate of the production costs.

D.2 Manufacturing routes

The non-ferrous metals industry includes a number of metals distinguished from the ferrous ones thanks to their non-magnetic properties and their resistance to corrosion. As already mentioned, the study is limited to aluminium, copper and zinc. This section includes the description of the manufacturing routes of these three metals. Detailed descriptions can be found in the literature (for aluminium [EAA, 2013; EC, 2014b], for copper [Ullmann's Encyclopaedia, 2012a; EC, 2014b] and for zinc [Ullmann's Encyclopaedia, 2012b; EC, 2014b]).

2.1 Aluminium

Figure 75 presents the whole (though simplified) life cycle material flow of aluminium. As this figure shows, primary aluminium production uses alumina as raw material. Alumina production requires mining of bauxite (mineral ore made up by a mixture of aluminium hydroxides, oxyhydroxides and other impurities) and the subsequent extraction of alumina (aluminium oxide) according to the Bayer process. In this process bauxite is washed with a hot solution of sodium hydroxide at 250 °C, dissolving aluminium hydroxide. The other components of bauxite do not dissolve and can be filtered out as solid impurities (red mud). Afterwards, the hydroxide solution is cooled and the aluminium hydroxide precipitates out. When heated to 1 050 °C, the aluminium hydroxide decomposes to alumina, giving off water vapour in the process.

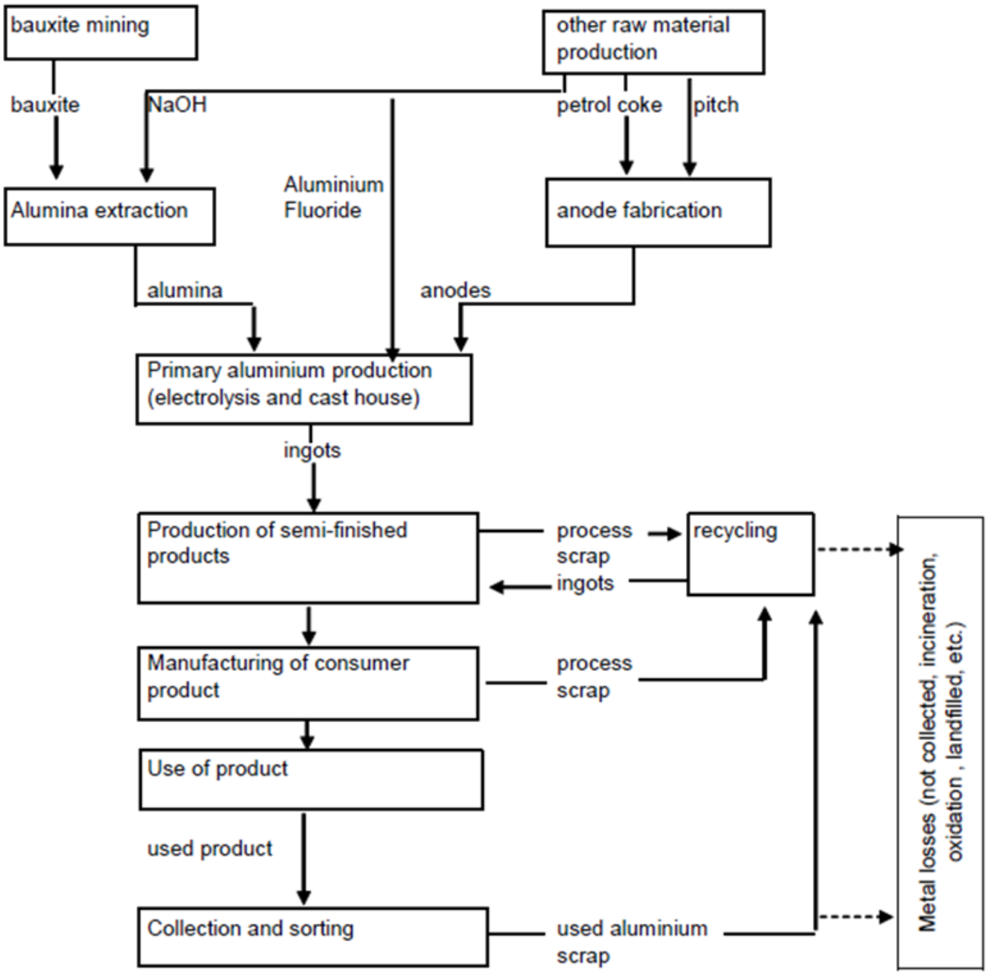


Figure 75: Simplified life cycle material flow chart of an aluminium product [EAA, 2013]

Primary aluminium production by the Hall-Héroult process involves dissolving the alumina (Al_2O_3) in molten cryolite (Na_3AlF_6) and electrolysing the molten salt. The presence of cryolite reduces the melting point of the alumina, facilitating the electrolysis. In the operation of the cell, aluminium is deposited on the cathode, whereas the oxygen from the alumina is combined with the carbon from the anode to produce CO_2. The main technologies using the Hall-Héroult process differ in how the anode is produced. In the Söderberg technologies it is fabricated in situ adding pitch to the top of the anode. In the prebake technologies the anodes are baked in large gas-fired ovens and later transferred to the cell. Most of the EU facilities have the prebake anode production integrated, and one third of them buy prebake anode on the market.

Regarding anode carbon as a fuel, total energy consumption per tonne of sawn aluminium ingot at the cast house amounts to 80 GJ, out of which around 50 GJ is electricity mainly (97 %) consumed in the electrolysis process. According to [EAA, 2013], in the EU and in EFTA countries (Iceland, Norway and Switzerland) electricity consumption in 2010 was 14.9 MWh/t of aluminium. Although the global level is slightly higher (15.3 MWh), there is high variability in the individual values; the electricity consumption of the best performers is close to 13 MWh/t [CEPS, 2013a].

On the other hand, production of secondary aluminium from scrap is less energy intensive. Secondary aluminium can be produced from new scrap in remelters (new scrap is produced during fabrication of aluminium products) and from old scrap in refiners (old scrap is the aluminium recovered after product use). Production of one tonne of ingot from clean process scrap in a remelter requires about 3.8 GJ/t of thermal energy and 0.45 GJ/t of electricity [EAA, 2013]. This is only a fraction of the energy consumption per tonne of primary aluminium production. Recycling of old scrap uses somewhat more energy because of the required scrap preparation step.

2.2 Copper

There are two processes to produce primary copper: hydrometallurgical or pyrometallurgical. The first process is usually applied in low-grade oxidised or mixed ores. It is usually applied in mine sites and represents approximately 20 % of the primary copper production worldwide [Ullmann's Encyclopaedia, 2012a; EC, 2014b]. Copper is a typical chalcophilic element and as a result its principal minerals are sulphides. Nowadays, low-grade or poor sulphide ores ([33]) are the main source of more than 80 % of primary copper, obtained following the pyrometallurgical route [Ullmann's Encyclopaedia, 2012a; EC, 2014b]. The product of both processes is copper cathodes.

The sulphuric concentrates that leave the mines consist of 15-45 % copper in complex copper/iron sulphides and derive from beneficiation by flotation of ores containing only 0.2-2 % copper [EC, 2014b]. Alternatives to this pre-treatment would involve higher consumption of energy, higher transport costs and large furnace capacities [Ullmann's Encyclopaedia, 2012a].

A generic flow diagram of the principal process for extracting copper from sulphide ores is depicted in Figure 76. The pyrometallurgical route in general involves five steps:

1. roasting
2. smelting
3. converting
4. refining and
5. electrorefining.

([33]) The expression 'low-grade or poor' refers to the copper content of the ore.

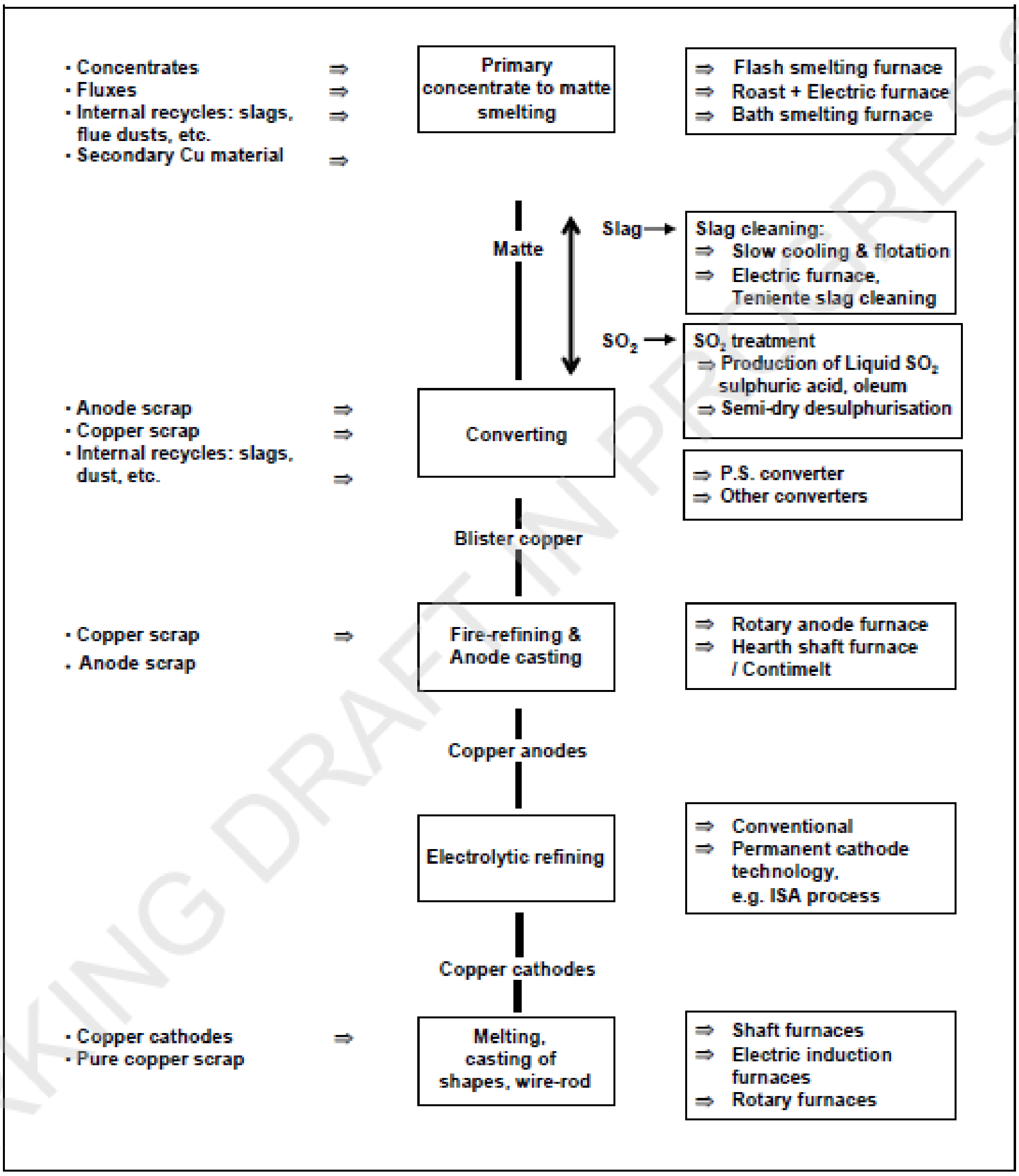


Figure 76: Principal generic process for extracting copper from sulphide ore [EC, 2014b]

Roasting is a preparation step. It results in drying the concentrates, oxidising a part of the iron present, controlling the sulphur content, partially removing volatile impurities and preheating the feed. Most of the sulphur is removed as sulphur dioxide, which can be captured and converted to sulphuric acid.

Roasting and smelting are usually carried out simultaneously [EC, 2014b]. There are several smelting technologies, with flash smelting and bath smelting (e.g. reverberatory) being the two main ones [EC, 2014b]. The degree of oxygen enrichment is the major difference between them. The product of smelting is two immiscible molten phases: matte and slag. The first one is a heavier phase of a mixture of copper (35-68 % Cu [Minerals UK, 2007]) and iron sulphide, while the latter is an oxide phase rich in iron (30-40 %) and silica that usually floats to the top. The main component of the slag is fayalite (Fe_2SiO_4). On the other hand, the main equilibrium in copper matte smelting is between copper and iron oxides and sulphides:

$$Cu_2O + FeS \leftrightarrow Cu_2S + FeO$$

Matte, usually in the molten phase, is further processed in the conversion step by blowing an air/oxygen mixture, to result in products with higher copper concentrations. The conventional converting is a batch process that yields in the first stage Cu_2S with 75-80 %wt Cu, known as white metal, while in the second stage averaging 98-99 %wt Cu, known as blister copper. Continuous matte converting is a second option, resulting also in blister copper.

The next step is fire refining, for further purification of blister copper. It involves the addition of air to oxidise impurities (without removing the precious metals) and remove final traces of sulphur and then a reducing agent (such as natural gas or propane) to remove oxygen dissolved in the liquid copper. Scrap can also be added in this process together with the blister copper. The final product from this step is cast into anodes.

The last step of the pyrometallurgical route is the electrolytic refining, yielding copper with high electrical conductivity and separating the valuable impurities, such as the precious metals. The basic principle of it is an electrolytic cell with a cast copper anode and a cathode in an electrolyte containing copper sulphate and sulphuric acid. Copper ions from the anode are dissolved into the electrolyte and then deposited onto the cathode. The valuable impurities can be found either in the electrolyte (e.g. less noble metals such as nickel) or as an anode slime on the electrolytic cell (e.g. more precious metals such as selenium and tellurium). These are recovered with further processing. The final product of this step is copper cathode with purity levels between 99.97 and 99.99 %.

Whether all or only some of these steps are followed depends on the quality of the ore used. The pyrometallurgical route can be roughly described as a process to separate the sulphide ore concentrates in three main elements: crude copper, iron(II) silicate slag and sulphur dioxide. Copper cathodes, the final product of the pyrometallurgical or hydrometallurgical routes, can be melted and cast in the different shapes of semi-finalised products, such as billets, cakes or wide rods.

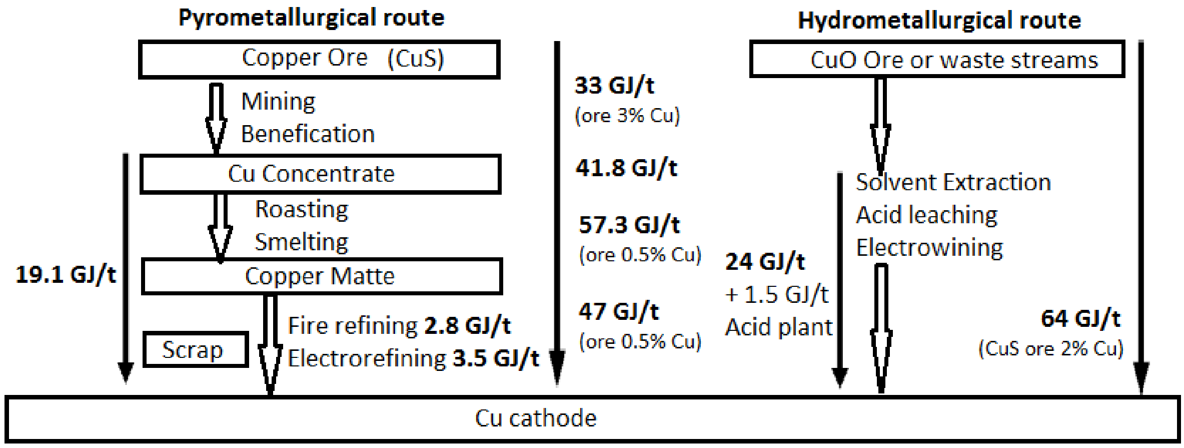


Figure 77: Energy requirements for copper production [BIR, 2008]

The energy requirement of copper production from copper concentrates depends on the concentrate, the smelting unit used and the degree of oxygen enrichment and is 14-20 GJ/t copper cathodes in Europe [EC, 2014b]. The electricity consumed by the electrorefining step is around 300-400 kWh/t_{Cu} but it strongly depends on the purity of the anodes electrorefined and can be considerably higher in the case of high impurity [EC, 2014b]. In the United States the theoretical energy requirement for conventional smelting is 36-46.5 GJ/t [BCS, 2002]. Figure 77 summarises the energy requirements for primary copper production [BIR, 2008]. For the pyrometallurgical route the differences in the values reported in the figure are due to different ore grades [Ayres et al., 2002]. Techniques to recover waste heat can increase energy efficiency and reduce external fuel consumption.

Copper's recycling value is high and as a result old scrap of premium quality can hold up to 95 % of the value of primary metal [ECORYS, 2011]. Almost all new or process scrap and a large percentage of old scrap is recycled [EC, 2014b]. It is estimated that about 40 % of copper in the EU is covered by secondary raw materials [EC, 2014b], while the percentage at global scale was about 20 % in 2012 (Figure 78).

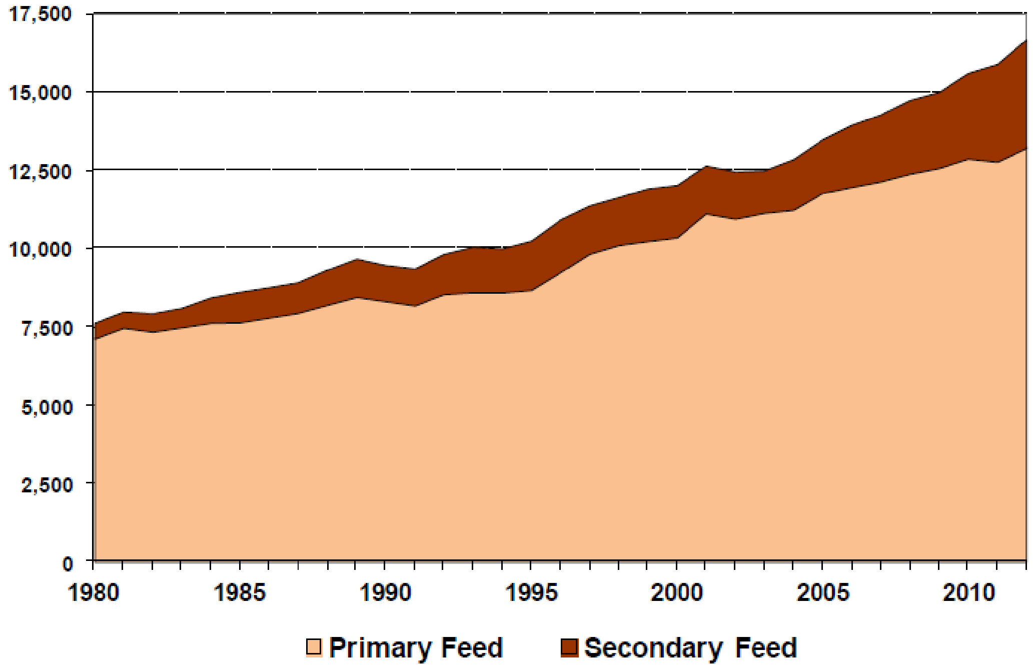


Figure 78: World copper smelter production 1980-2012 (unit: thousand metric tonnes of copper) [ICSG, 2014]

The processes used for copper recycling depend on the copper content of the secondary raw material, its size distribution and the contaminants that may be present. The quality of secondary raw materials varies significantly, as they can contain organic materials such as coatings or be oily in nature [EC, 2014b]. The degree of organic contamination plays an important role also in the potential emissions [EC, 2014b]. The energy savings of secondary copper production (about 7.3 GJ/t [BRI, 2008]) are around 35 and 85 % [BRI, 2008; ECORYS, 2011] of the energy required for primary production.

2.3 Zinc

As in the case of copper, zinc can be produced from primary raw materials either by pyrometallurgical or hydrometallurgical methods. While in the case of copper pyrometallurgical routes are the main production method, in the case of zinc hydrometallurgical routes account for about 90 % of the total world zinc output and the majority of production in the EU [EC, 2014b]. Therefore, only the hydrometallurgical process will be presented briefly.

Zinc, similar to copper, is a highly chalcophilic element, thus it is usually found in sulphidic concentrate [Ullmann's Encyclopaedia, 2012b]. The most important zinc mineral currently is zinc blende or sphalerite (ZnS), which has a theoretical composition of 67.1 % zinc (Zn) and 32.9 % sulphur (S). The most important impurity of sphalerite is iron in the form of iron(II) sulphide (FeS), but also sulphides of lead (Pb), cadmium (Cd), manganese (Mn) and copper (Cu) are often present. In addition, it often contains small amounts of arsenic (As) , tin (Sn) , bismuth (Bi), cobalt (Co), nickel (Ni), mercury

(Hg), indium (In), thallium (Tl), gallium (Ga), germanium (Ge), silver (Ag) and gold (Au) [Ullmann's Encyclopaedia, 2012b].

The main steps of the hydrometallurgical process are:

1. roasting
2. calcine processing
3. leaching
4. purification and
5. electrolysis.

The starting material should be oxidic, although zinc is usually found in sulphidic concentrates [Ullmann's Encyclopaedia, 2012b]. They therefore require conversion by roasting, which removes the sulphur as SO_2 and impurities such as mercury and halogens. There is no need for additional fuel, as the following reaction is exothermic:

$$2\ ZnS + 3\ O_2 \leftrightarrow 2\ ZnO + 2\ SO_2$$

The zinc oxide (zinc calcine) is then led to the leaching section, where it is treated with a gradually increasing strength of hot sulphuric acid, according to the following reaction:

$$ZnO + H_2SO_4 \rightarrow ZnSO_4 + H_2O$$

The product of this process is a neutral zinc sulphate solution with 70-95 % zinc, as well as other metals such as copper (Cu), cadmium (Cd), cobalt (Co) and nickel (Ni). The next step of the process aims at eliminating the impurities that might still be present in the unpurified neutral liquors. Their existence can lead to lower current efficiency in the electrolysis, the presence of impurities also in the zinc cathode and adverse effects on the anode and cathode.

Table 34: Energy requirements of various zinc processes [EC, 2014b]

Process	Product	Electricity (kWh/t)	Coke	Natural gas (Nm^3/t)
Roast-leach-electrowin (1)	Zinc 99.995 %	3 850-4 905	0.48 GJ/t	
Imperial Smelting Furnace (2) New Jersey distillation	Zinc metal	1 050 750	1 100 kg/t 785 kg/t	220 160
Slag fuming	Slag	150	250 kg/t	
Waelz kiln (3) (without washing)	WO unwashed	240	480 kg/t	4
Waelz kiln (2-stage washing)	WO washed	300	540 kg/t	38
Waelz kiln (3-stage washing and crystallisation)	WO washed	360	540 kg/t	19

(1) The RLE process is practically the same as the hydrometallurgical route and the total energy required is 13.86–20 GJ/t without energy credits.
(2) The ISF is used in the pyrometallurgical route.
(3) Concerns secondary routes.

The purified solution finally enters a cell house, where zinc is isolated using lead anodes and aluminium cathodes. Zinc is deposited on the cathodes, from where it is stripped off, and at the anodes oxygen gas and sulphuric acid are produced. The zinc collected is melted in induction furnaces and cast into slabs and ingots.

The energy requirements of different zinc processes vary to a large extent and depend on the quality of feed and products, the use of waste heat and the production of by-products. Table 34 and Figure 79 summarise average energy consumption for the different zinc production processes.

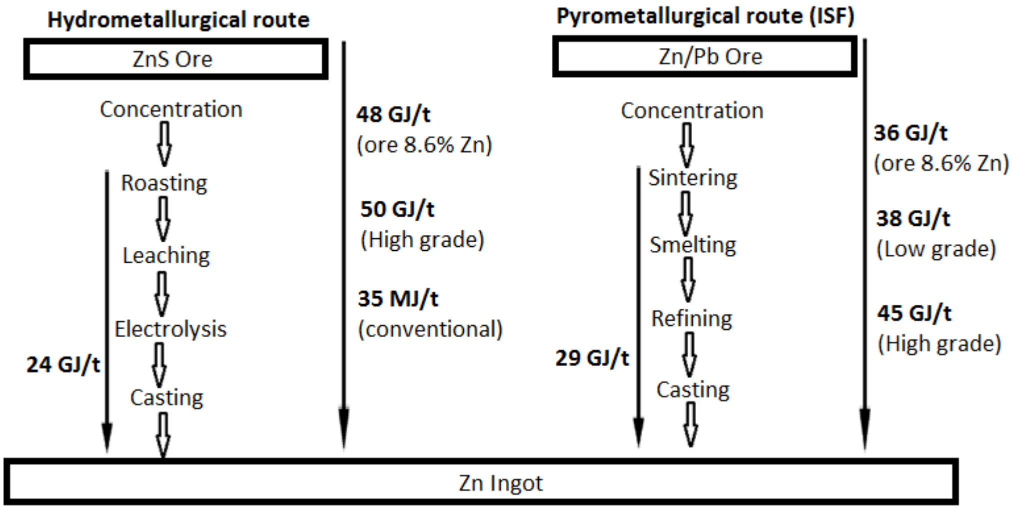


Figure 79: Energy requirements for zinc production [BIR, 2008]

Zinc recycling accounts for approximately 30 % of the annual zinc consumption in the EU and half of this quantity is recycled within the zinc industry itself [EC, 2014b].

D.3 Market and industry status

3.1 Aluminium

Aluminium is the most used non-ferrous metal. In 2013 global primary aluminium production was 47.6 Mt. With a production of 22 Mt China leads the ranking, followed by the EU and EFTA countries (4.6 Mt). Alone, the EU ranks in fifth position. Figure 80 shows the production shares of the main producers.

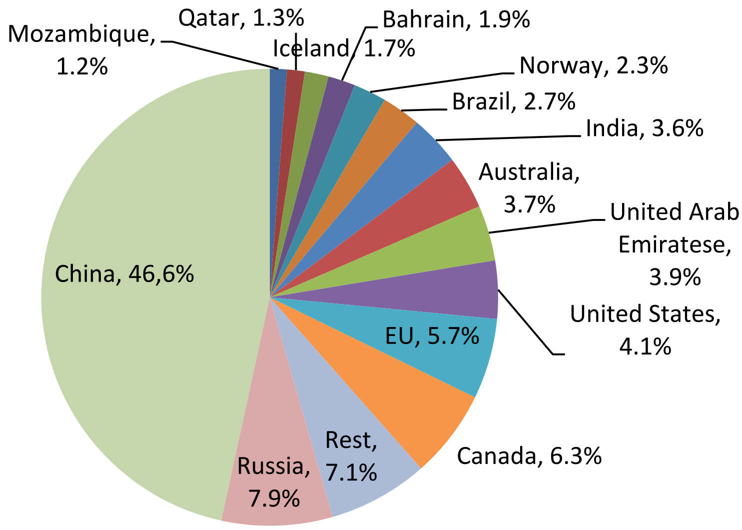


Figure 80: Primary aluminium production [USGS, 2015b]

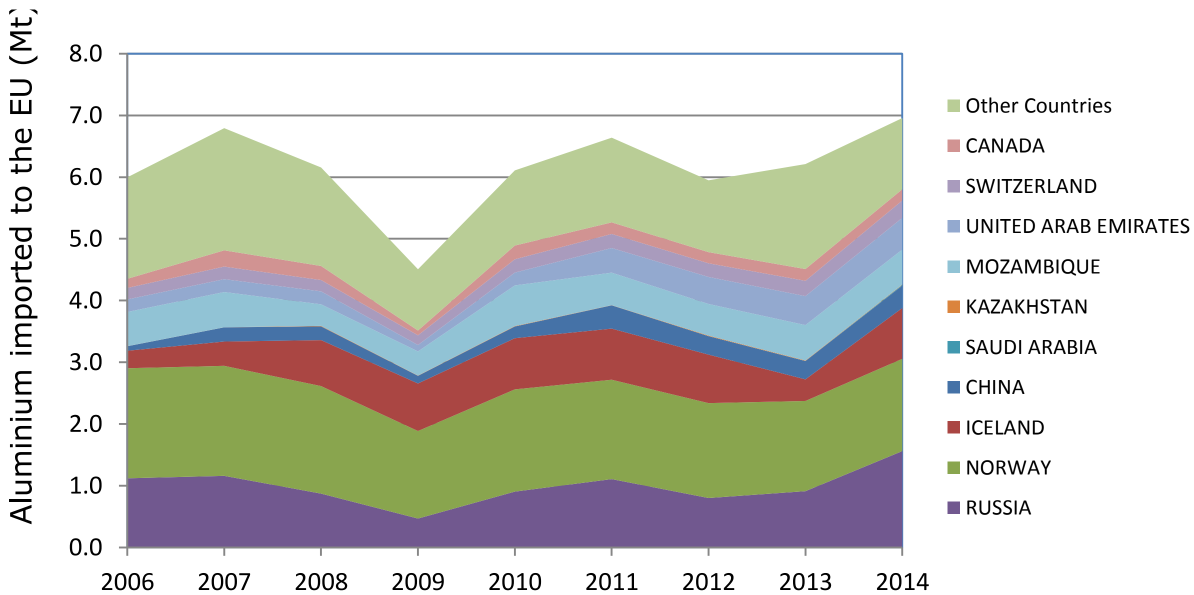


Figure 81: Primary aluminium imports into the EU (in Mt), excluding intra-trade flows

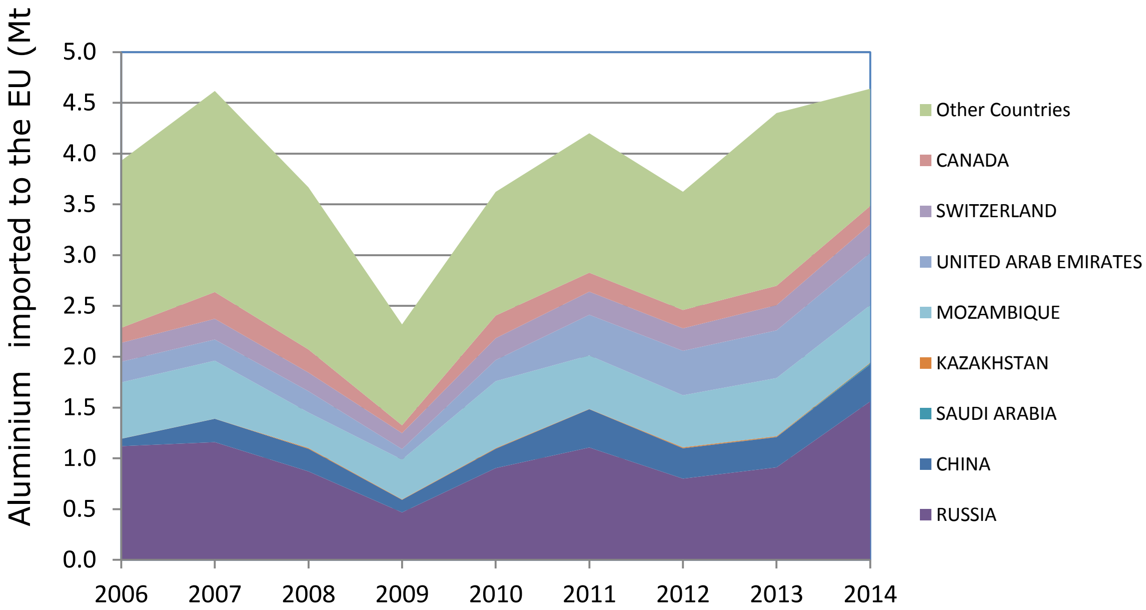


Figure 82: Primary aluminium imports into the EU and EFTA countries (in Mt), excluding intra-trade flows

Figure 81 and Figure 82 show the origin of imports of primary aluminium (products under category SITC 684) into the EU, and into the EU and EFTA countries together (both figures exclude intra-trade flows). In 2014 the imports from Norway and Russia into the EU each represented 20 % of the total primary aluminium imported (7.3 Mt). The percentage of imports from Iceland and China were 11.3 % and 5 % respectively, while the cumulated share of imports from Canada, Mozambique, Switzerland, Turkey and the United Arab Emirates amounted to 25.6 %.

3.2. Copper

In 2013 global copper mining production was estimated to be about 18.3 Mt [USGS, 2015a]. Chile is the largest producer with a share of 32 %, followed by China, Peru and the United States [USGS, 2015a]. In the EU important copper mining production can be found in Poland (about 429 kt copper extracted in 2013), Bulgaria (115 kt), Spain (104 kt), Sweden (83 kt), Portugal (77 kt), Finland, Romania and Cyprus [UK Minerals, 2015].

Global smelter ([34]) production in 2013 reached between 13.8 Mt [UK Minerals, 2015] and 16.8 Mt [ICSG, 2014]. China was the largest producer of blister and anode with between 3.7 Mt [UK Minerals, 2015] and 5.7 Mt [ICSG, 2014]. The difference between the values is attributed to the fact that UK Minerals considers only primary copper, while ICSG also includes secondary material. Figure 83 shows the world distribution of copper produced in smelters in the world. EU-28 produced about 1.5 Mt primary copper, with Bulgaria, Germany, Spain and Poland accounting for more than 80 % [UK Minerals, 2015].

([34]) Smelters produce copper anodes following the first steps of the pyrometallurgical route.

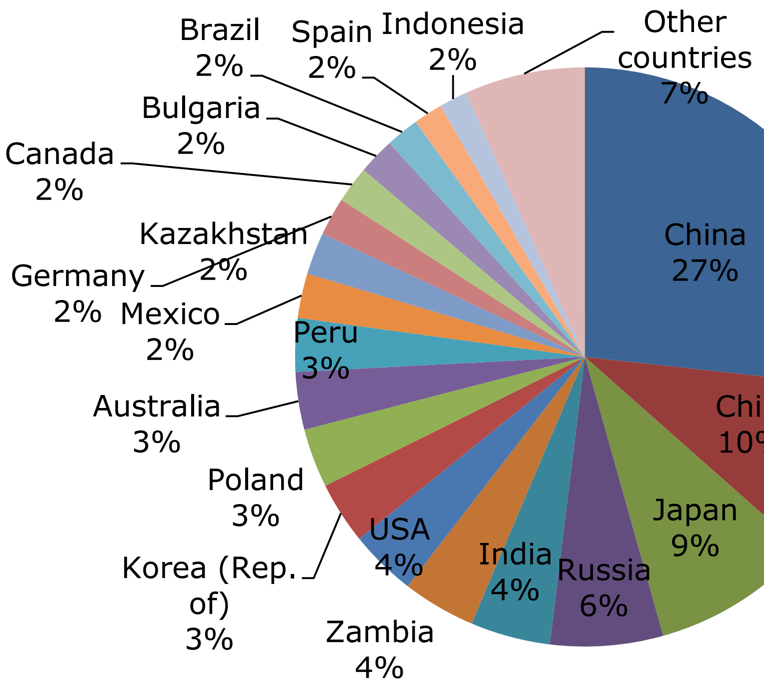
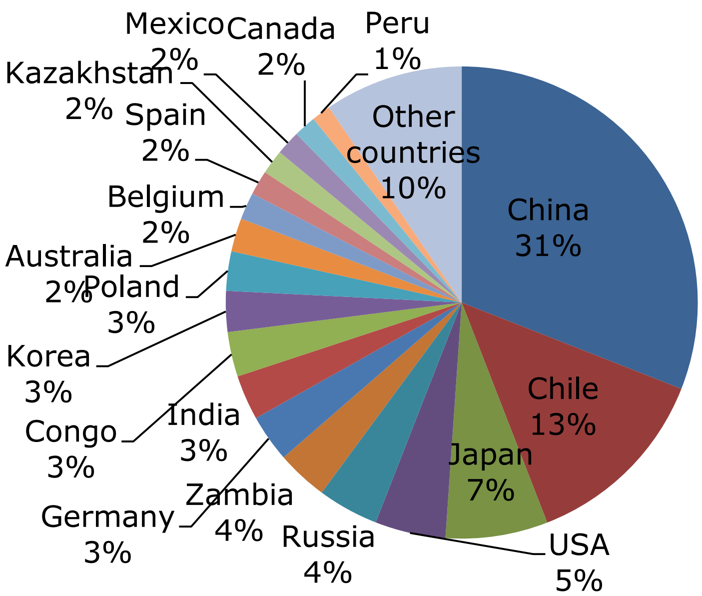


Figure 83: Distribution of copper smelter production in the world [UK Minerals, 2015]

On the other hand, global copper refinery ([35]) production was 20.9 Mt, including 3.8 Mt of secondary refined production [ICSG, 2014; UK Minerals, 2015]. China is again the largest producer accounting for 31 % of global copper refinery production and EU-28 accounts for about 13 % with a total of about 2.7 Mt (Figure 84) [UK Minerals, 2015]. Table 35 shows the copper mine, smelter and refinery production in the EU-28 Member States.



([35]) Copper refineries produce copper cathodes following the last steps of the pyrometallurgical route.

Figure 84: Distribution of copper refinery production in the world [UK Minerals, 2015]

As can be seen from the balance between mined copper and smelted or refined copper (Table 35), the EU is highly reliant on imports of ores and concentrates. The EU is importing mainly from Brazil, Chile and Peru, and the EU-28 internal trade of copper ores and concentrates reached 7.65 Mt in 2012 and 8.6 Mt in 2013, while the EU-28 external trade was 35.4 Mt in 2012, 35.7 Mt in 2013 and 39.6 Mt in 2014 [Eurostat, 2015a].

Table 35: Copper (mine, smelter and refinery) production in EU-28 [UK Minerals, 2015]

Country	Mine production	Smelter production	Refinery production
Austria			4.0 %
Belgium			14.6 %
Bulgaria	13.5 %	18.6 %	8.6 %
Germany		19.5 %	25.4
Spain	12.3 %	14.8 %	13.1 %
Italy			0.2 %
Cyprus	0.4 %		0.2 %
Poland	50.3 %	30.0 %	21.1 %
Portugal	9.0 %		
Romania	0.8 %		
Finland	4.0 %	7.8 %	5.1 %
Sweden	9.7 %	9.3 %	7.7 %
EU-28	854 kt	1 518 kt	2 674 kt

Figure 85 shows the origin of imports of refined copper in the form of cathodes and sections of cathodes (products under category CN8) [Eurostat, 2015b]. In 2013 the total extra-EU imports of refined copper in the form of cathodes and sections of cathodes were 0.97 Mt and the exports were 0.58 Mt [Eurostat, 2015b]. The share of imports from Chile was 44 %, while together Chile, China, Peru and Zambia represented 54 % of the extra-EU imports. Copper cathodes imports from China in 2013 were only 0.4 % of the total imports.

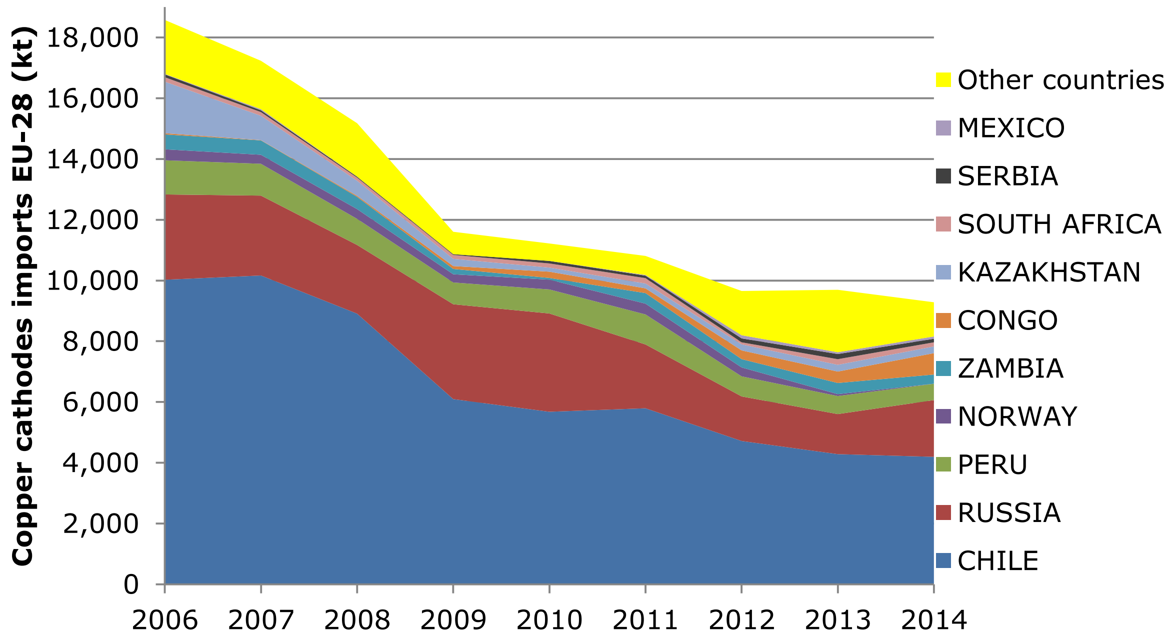


Figure 85: Country of origin of imports into the EU-28 of refined copper in the form of cathodes and sections of cathodes [Eurostat, 2015b]

3.3 Zinc

Zinc is the third most used non-ferrous metal, behind aluminium and copper. In 2013 global zinc production was estimated to be about 13.5 Mt, with China leading mine production [USGS, 2015b; UK Minerals, 2015]. The EU mined 735.5 kt zinc in 2013, about 2.6 % less than in 2012 [UK Minerals, 2015]. About 45 % of it was produced by Ireland and 25 % by Sweden. There are also zinc mines in Bulgaria, Greece, Spain, Portugal, Romania and Finland [UK Minerals, 2015].

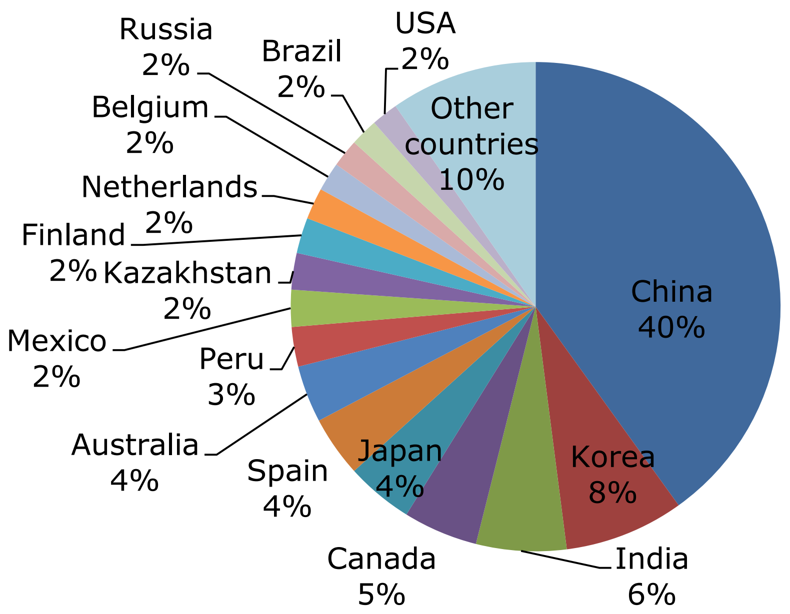


Figure 86: Distribution of zinc slab production in the world [UK Minerals, 2015]

Global zinc slab production in 2013 reached 13.2 Mt [UK Minerals, 2015]. China was once again the largest producer with more than 5.3 Mt. South Korea the second biggest producer with 1.0 Mt (Figure 86). The EU-28 produced about 2.0 Mt zinc slab, with Belgium, Finland, the Netherlands and Spain accounting for almost 70 % [UK Minerals, 2015]. EU production per country is summarised in Table 36.

Table 36: Zinc (mine and slab) production in EU-28 and Norway [UK Minerals, 2015].

Country	Mine production	Slab production
Belgium		12.5 %
Bulgaria	1.8 %	3.6 %
Germany		8.0 %
Ireland	44.4 %	
Greece	3.1 %	
Spain	3.4 %	26.3 %
France		7.6 %
Italy		5.5 %
Netherlands		13.7 %
Poland	10.2 %	7.3 %
Portugal	7.3 %	
Romania	0.3 %	
Finland	5.5 %	15.5 %
Sweden	24.0 %	
EU-28	735.5kt	2 012 kt
Norway		143.4 kt

Figure 87 shows the origin of imports of unwrought zinc (product under category CN8) [Eurostat, 2015b]. In 2013 the total extra-EU imports of refined zinc were 0.16 Mt and the exports were 0.38 Mt [Eurostat, 2015b]. The share of imports from the countries of interest in this study was only 2.4 %. As it can be seen from the figure, the main countries from which the EU is importing zinc are Norway and Namibia. By including these two countries, the share of imports reaches 74.9 %.

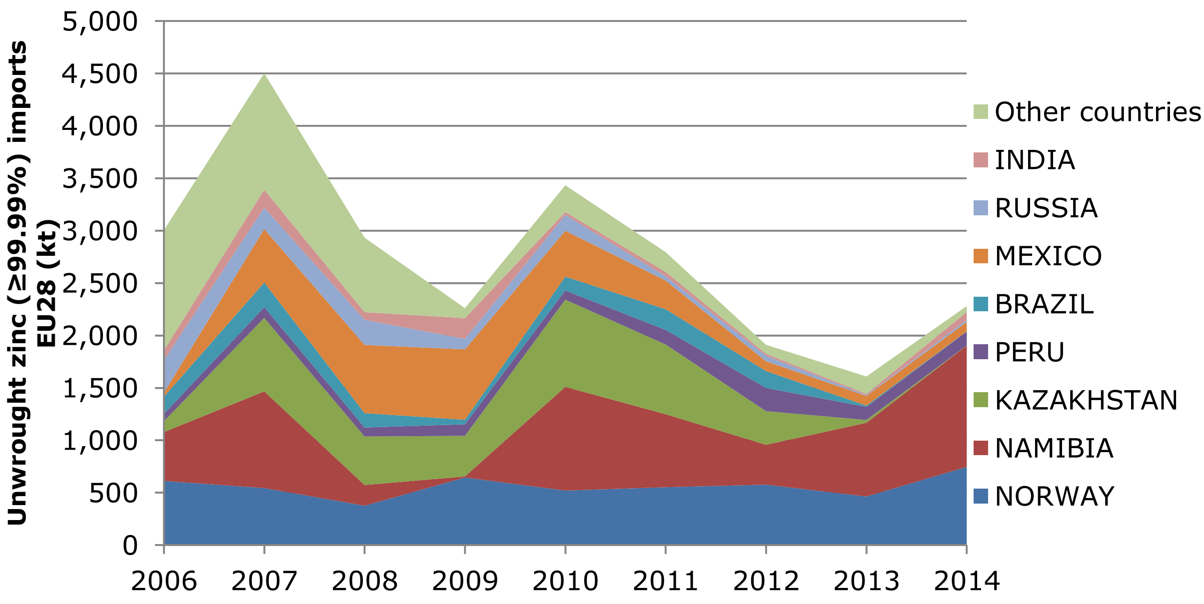


Figure 87: Country of origin of imports into the EU-28 of unwrought zinc containing by weight ≥99.99 % zinc [Eurostat, 2015b]

D.4 Research protocol

For all three metals of interest, a bottom-up approach was followed to assess the different production costs. The study provides an analysis using 2012 and 2013 as base years. This section describes the methodology applied for the aluminium, copper and zinc.

4.1 Aluminium

For the aluminium industry, this document follows a bottom-up approach to assess the different costs of primary aluminium production; this bottom-up approach is based on the information at facility level provided in [Pawlek, 2014]. The small specific energy consumption of production of secondary aluminium (4.2 GJ/t compared to 80 GJ/t of primary aluminium production) and the fact that its costs are mainly dominated by scrap prices (that accounts for around 70 % of the production cost of this route) makes the analysis of secondary production costs uneventful. Moreover, the high number of secondary producers (in the EU there are over 270 secondary aluminium producers compared to 16 smelters of primary aluminium) makes a bottom-up approach unfeasible for the secondary production route.

Worldwide, only a small number of smelters are associated with an alumina refinery plant (in the EU only two out of 16 smelters have an alumina refinery), the rest of the smelters buy the alumina on the market with long-term contracts. Therefore, for both kinds of facilities (with and without alumina refinery integrated) we treat the alumina cost as a raw material cost, incorporating either the estimated production costs in the alumina refinery or the alumina price on the market. When the anode manufacturing takes place in an integrated facility, its cost estimation includes the same components (raw materials, energy and labour) and is aggregated to the same cost categories as primary aluminium production. For the rest of the facilities that buy the anode on the market, we include an estimation of the anode prices as a raw material cost.

In order to include the two countries which, as mentioned in Section 3.5, have the highest exports to the EU, we add Iceland and Norway to the initial list of countries within scope (China, Kazakhstan, Russia, Saudi Arabia). Simultaneously, we disregard the Saudi Arabian production since their only plant (Ras Al Khair, with a capacity of 0.74 Mt) was under construction during 2012 and only entered in operation by the end of 2013 [MA'ADEN, 2015].

Table 37: Capacity and number of aluminium smelters in operation or in construction

	Number of smelters	Number of smelters in construction	Total capacity Mt
Kazakhstan	1	0	0.24
Iceland	3	1	0.65
Norway	7	0	1.33
Russia	7	2	3.56
China	119	19	26.87
EU	16	0	3.11

4.2 Copper

In the case of copper, the bottom-up approach is based on information from the Wood Mackenzie database [Wood Mackenzie, 2015a; Wood Mackenzie, 2015b]. The database covers more than 90 % of total primary production from copper smelters worldwide and about 93 % of the Chinese copper production in 2013. It includes information directly from the plants and is one of the most detailed commercial databases containing actual data.

The countries in the initial list included China, Kazakhstan, Russia and Saudi Arabia/Qatar. However, since there is no information available about all of them, we have replaced Kazakhstan, Russia and Saudi Arabia/Qatar with Chile, Peru and Zambia from which the EU imports copper cathodes. Therefore, based on the origin of imports into the EU-28 in Section 3.2 (Figure 85) and on the availability of commercial data, our analysis includes the EU-28, Chile, China, Peru and Zambia.

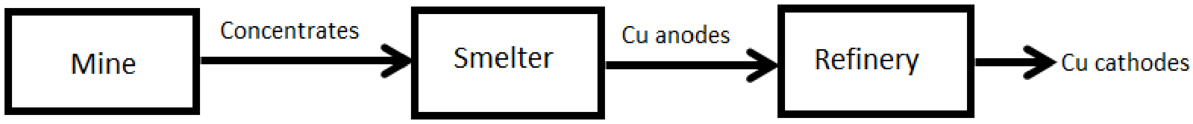


Figure 88: Generic structure of the copper industry

The industry consists of two parts: copper smelters that process concentrates to produce copper anodes and copper refineries that produce copper cathodes from copper anodes (Figure 88). As a result, the two different types of facilities are distinguished in our analysis. The final product of smelters is copper anodes and the final product of refineries is copper cathodes.

The analysis is based mainly on primary production of copper. Savings in the case of secondary production can reach 85 %, thus leading to consumptions as low as 2.1 $GJ/t_{cathode}$, compared to almost 20 $GJ/t_{cathode}$ of the energy-efficient primary copper industry in the EU. As the share of primary production is much higher (Figure 78) and energy consumption is at least 10 times higher than the one of secondary production, and as both energy consumption and the costs in the case of secondary copper are strongly dependent on the quality of scrap, any potential comparison of secondary production costs among countries is of little interest. Note that other studies [ECORYS, 2011] also report difficulties in distinguishing between energy costs for primary and secondary processing.

Table 38 shows the number of facilities included in the database, and therefore in this study. The differences between 2012 and 2013 were that a new smelter started operating in China, while a copper refinery was closed down, and another one started. In both cases the total installed capacity in China increased by 0.5 Mt.

Table 38: Number and capacity of copper smelters and refineries in operation in 2012

	Copper smelters		Copper refineries	
	2012		2012	
	Number	Capacity (Mt)	Number	Capacity (Mt)
EU	8	2.5	12	2.7
Chile	7	2.0	3	1.1
China	13	4.4	16	5.1
Peru	1	0.4	1	0.3
Zambia	3	0.6	2	0.5

4.3 Zinc

As in the case of copper, the bottom-up approach is based on information from the Wood Mackenzie database [2015a]. The global coverage of the database is over 80 %, including all of China with the exception of the very small smelters, resulting in about 65 % total production coverage [Wood Mackenzie, 2015c].

The countries of interest in this case are EU-28, China, Kazakhstan, Russia and Saudi Arabia/Qatar. There are no zinc smelters in Qatar and in Saudi Arabia there was a smelter planned in 2006, which was never realised. In addition to these countries, Namibia and Norway are added to also cover the countries from which the EU is importing the most unwrought zinc.

In a similar way as for copper, the secondary route of zinc is not considered fully in this study. Nevertheless, half of zinc recycling takes place within the primary route [EC, 2014b].

Table 39 shows the number of smelters included in the database, and therefore in this study. The only difference between 2012 and 2013 was that a smelter in Bulgaria closed down.

Table 39: Number and capacity of zinc smelters in 2012 and 2013

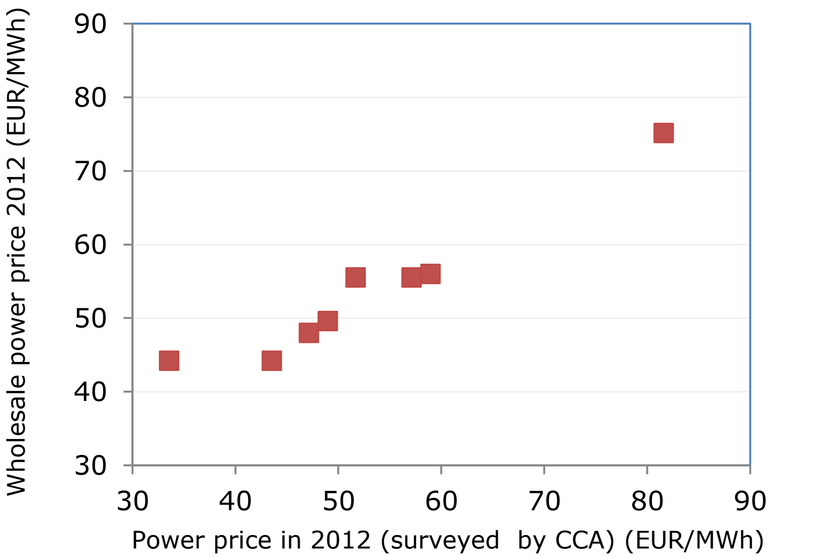
	Number	Capacity (Mt)
EU	11	2.0
China	6	1.0
Kazakhstan	2	0.3
Namibia	1	0.2
Norway	1	0.2
Russia	2	0.3

D.5 Prices of energy, raw materials and resources

5.1 Aluminium

The information provided by the statistics about power prices for big power consumers is quite limited. The information collected by Eurostat for consumption band Ig ([36]) (>150 000 MWh) is based on voluntary reporting. Moreover, the prices in this band might result from negotiated contracts, varying from one supplier to another. To overcome this limitation, the CEPS report [CEPS, 2013a] surveyed the prices paid by a sample of 11 smelters, three of which had a bilateral contract with a power provider. In this report we use the information from the CEPS report to check the validity of using the wholesale power prices as proxy for the electricity price paid by large consumers in 2012 and 2013. When in Figure 89 we disregard the three lowest electricity prices of CEPS's sample (bilateral contracts), we can check that there is a clear relationship between the increasing power prices of the CEPS report in 2012 (in the horizontal axis) and the increasing wholesale electricity prices in the countries with primary aluminium producers (in the vertical axis). Since this correlation is quite high (0.97) we use the wholesale power prices as a good proxy for the electricity price paid by each smelter for the two years considered. The information on bilateral contracts is included in the analysis by adding three fictitious facilities with all the characteristics of an average EU smelter, but with the electricity price of those three bilateral contracts.

([36]) The information for band Ig is the average of the electricity prices of eight out of the 28 EU Member States (Bulgaria, Greece, Spain, Italy, Hungary, Poland, Slovakia and United Kingdom).



(excluding the three lowest prices that correspond to bilateral contracts)

Figure 89: Relationship between the wholesale power prices and the power prices paid to the aluminium smelters surveyed by CEPS [CEPS, 2013a]

The values of electricity prices in Table 40 for Norway and Iceland come from [SN, 2015] and [Landsvirkjun 2014] respectively. For the rest of the countries they are estimated using known values in other consumption bands (from the information gathered to produce the first working document about the iron and steel industry) and applying the same ratio observed among those consumption bands and the wholesale market price in the EU. The three electricity prices from bilateral contracts [EC, 2015; CEPS, 2013a] are also included when estimating the minimum and weighted average electricity price in the EU.

Table 40: Prices of energy used for the average aluminium manufacturer, all prices in EUR/MWh [SN, 2015; Landsvirkjun 2014; EC, 2015; EC, 2015b; CEPS, 2013a; Djukanovic, 2012; Pawlek, 2014]

(EUR/MWh)			**CHN**	**ISL**	**KAZ**	**NOR**	**RUS**	**EU**
Electricity price	2012	Min	41.6				13.6	11.9
		Average	49.9	20.2	21.6	28.4	21.5	42.5
		Max	63.4				38.9	56.0
	2013	Min	46.5				14.3	11.9
		Average	53.5	19.7	20.3	30.7	22.6	37.8
		Max	67.4				40.8	58.4
NG (Band i4)	2012	Min						25.5
		Average	28.7	16.7	9.2	16.7	11.3	34.6
		Max						56.2
	2013	Min						24.5
		Average	32.4	15.5	9.2	15.5	10.7	35.3
		Max						48.1

The low electricity prices in Iceland, Norway and Russia are mainly explained by the hydroelectric origin of the power consumed. In Iceland 75 % of the power generation comes from hydroelectricity, and the remaining is geothermal. Moreover, the Icelandic aluminium industry accounts for around 75 % of electricity consumption, and indeed electricity prices are indexed to the aluminium price. The estimation of Chinese prices incorporates the fact that production in some provinces, accounting for almost 20 % of production, benefit from a discount of 80 yuan/MWh [Djukanovic, 2012] and from the overall historical variability observed in [Pawlek, 2014].

In the EU, when excluding bilateral contracts, the estimated average electricity price in the wholesale market is 47.0 and 41.1 EUR/MWh in 2012 and 2013 respectively. These prices are lower than the average electricity price for Chinese smelters but much higher than for the rest of countries.

Table 41: Prices of raw materials in the aluminium industry [UN, 2015, USGS, 2015c]

Product	**EUR 2012/t product**	**EUR 2013/t product**
Alumina	321.3	307.0
Anode	272-527	304-447
Green coke blend	52-101	61-89

The values in Table 41 and Table 42 give the range observed in the countries under study for the raw materials. For facilities with alumina refineries the price of the alumina used corresponds to the estimated production cost in each refinery. The green coke blend is consumed in the manufacture of prebaked anode. Although the scrap price is not included in Table 41, in line with the average values observed [Argus Media, 2015], we assume an average value of 700 EUR/t for all countries. According to the EAA [EAA, 2013] there is a consumption of 0.125 t of scrap per tonne of casted aluminium in the EU and of 0.041 t in the rest of the countries.

The productivity values in Table 42 are estimated from [Pawlek, 2014], and the hourly labour cost comes from the data used from the first working document about the iron and steel industries.

Table 42: Productivity and manpower costs in the aluminium industry [Pawlek, 2014]

		Productivity t Al/man	**Hourly labour cost EUR/h 2012**	**Hourly labour cost EUR/h 2013**
China	Min	10		
	Average	119	5.1	5.6
	Max	315		
Iceland	Min	422		
	Average	655	34.5	33.1
	Max	750		
Kazakhstan	Average	362	3.0	3.0
Norway	Min	296		
	Average	480	34.5	33.1
	Max	564		
Russia	Min	78		
	Average	240	2.8	2.6
	Max	618		
EU	Min	86	6.7	6.7
	Average	362	26.2	26.0
	Max	455	34.1	34.2

5.2 Copper

The breakdown of costs in the case of copper followed in this study generally includes three components:

(a) energy

(b) labour and other costs

(c) credits.

Copper smelters are high consumers of energy, although to a much lesser extent than the aluminium smelters, as we will show in Section D.6. Table 43 shows the average, minimum and maximum prices for electricity, natural gas, fuel oil and coal reported by the different copper smelters. It is interesting to note that in 2013 there was a decrease in energy costs. Chile had the highest electricity price [Wood Mackenzie, 2015b]. In this country there is a shortage of electrical power as a result of increasing consumption and lack of investment in the power generation infrastructure.

Manufacturing processes of copper refineries are power intensive and are therefore sensitive to variations in power tariffs. The energy cost is mainly driven by the cost of electricity; however, some heating is also required to maintain electrolyte temperature. Although part of the heating is provided by the electrical resistance of the solution, it is normally satisfied by external sources such as steam. Steam may be provided by boilers, but when the copper refinery is located close to a smelter, the latter can usually provide steam at a competitive price. The steam prices reported by the copper refineries are included in Table 43.

'Labour and other costs' include salaries for supervision, operation and maintenance, as well as maintenance items, consumables and other on-site costs. Maintenance items generally include everything used to keep the smelter operational, while consumables include everything used to operate the smelter, such as flux ore, water oxygen etc. The range of items covered is wide and depends on the technology used that does not allow disaggregation of the cost. Other on-site costs include services such as water, communications, rates, property taxes and infrastructure costs such as general site maintenance. These costs depend on local factors and are not necessarily proportional to capacity.

Table 44 includes the labour costs reported by the copper smelters in the countries of interest and Table 44 by the copper refineries. It is interesting to note that the EU has the highest average productivity and that China has the widest range of productivities both in the case of smelters and in the case of copper refineries. The countries with the highest copper refinery productivity in the world in 2013 were Germany (0.6 hr/t Cu cathode) and Austria (0.7 hr/t Cu cathode).

Table 43: Prices of energy used and credits in the copper industry [Wood Mackenzie, 2015a]

			EU	Chile	China	Peru	Zambia
Electricity (EUR/MWh)	2012	Min	44.7	33.9	49.8	93.4	44.2
		Average	63.7	107.6	63.2		
		Max	77.1	158.6	75.5		
	2013	Min	34.5	33.6	51.3	86.2	43.3
		Average	59.2	105.9	62.0		
		Max	70.0	165.9	73.8		
Natural gas (EUR/MWh)	2012	Min	31.68	56.52	24.84		
		Average	37.44	62.28			
		Max	41.04	69.12			
	2013	Min	30.60	47.52	23.76		
		Average	39.60	55.80	25.92		
		Max	45.72	69.12	27.72		
Fuel oil (EUR/t)	2012	Min	506.32	468.40	486.46	575.60	586.46
		Average	569.39	577.47	527.37		
		Max	655.83	618.24	537.13		
	2013	Min	457.26	417.27	459.22	552.41	574.45
		Average	514.33	512.15	500.35		
		Max	546.72	556.74	533.54		
Coal (EUR/t)	2012	Min	74.53		54.73	116.58	55.15
		Average	92.97		70.25		55.98
		Max	111.41		82.37		56.80
	2013	Min	69.26		48.68	123.39	54.03
		Average	80.74		63.45		55.10
		Max	92.23		83.37		55.64
Steam (EUR/t)	2012	Min	6.88	2.86	0.69		15.56
		Average	13.91		10.28		
		Max	25.90		23.51		
	2013	Min	5.42	2.74	0.73		14.94
		Average	13.08		10.06		
		Max	21.51		23.46		
Sulphuric acid (EUR/t)	2012	Min	21.16	22.51	4.90	83.93	137.30
		Average	32.21	81.15	28.64		143.84
		Max	48.51	116.11	43.90		156.91
	2013	Min	14.98	13.55	2.16	51.34	99.00
		Average	21.51	57.79	10.25		106.16
		Max	37.71	104.66	25.07		120.47
Cathode premium (EUR/t_{Cu})	2012	Min	5.68	− 7.89	− 45.50	12.29	− 30.04
		Average	32.18	− 3.76	39.13		− 29.52
		Max	50.34	1.34	83.41		− 29.02
	2013	Min	− 3.63	− 11.22	− 39.15	− 56.15	− 34.24
		Average	28.04	− 5.55	35.61		− 28.89
		Max	43.69	0.86	74.07		− 24.99

Table 44: Productivity and manpower costs in copper smelters [Wood Mackenzie, 2015a]

		Productivity (t Cu anode/man)	Hourly labour cost (EUR/h) 2012	2013
EU	Min	207.0	10.09	10.09
	Average	489.1	25.79	25.15
	Max	990.5	48.70	49.40
Chile	Min	122.4	5.31	5.71
	Average	254.8	21.15	22.43
	Max	422.2	38.33	45.75
China	Min	60.1	0.68	0.62
	Average	260.6	2.37	2.46
	Max	954.4	3.45	3.65
Peru	Min			
	Average	403.1	12.88	14.58
	Max			
Zambia	Min	248.6	3.78	3.50
	Average	297.1	4.89	4.52
	Max	308.0	5.83	5.34

In most countries there are claims for high labour remuneration rates within the copper industry, mainly due to the increase in the copper price. Much of the wage inflation pressure to smelters originates in the mining industry, and it is notable that many of the smelters with the highest wages are those directly tied to a local mine, such as the majority of the Chilean smelters. Chilean copper refineries also have the highest labour costs on a national basis. The only exception is China, where wages in the industry are still well below the world average. Wages are paid in local currencies and the effect of the dollar and euro exchange rates on comparative rates is important.

Table 45: Productivity and manpower costs in copper refineries [Wood Mackenzie, 2015a]

		Productivity (t Cu cathode/man)	Hourly labour cost (EUR/h) 2012	2013
EU	Min	484.2	10.09	9.68
	Average	1 876.7	28.42	28.03
	Max	3 407.4	44.59	45.23
Chile	Min	491.5	12.93	13.16
	Average	585.3	25.70	26.73
	Max	728.5	42.04	40.61
China	Min	113.3	0.68	0.62
	Average	717.1	2.48	2.54
	Max	2 929.3	3.70	3.91
Peru	Average	597.2	11.13	14.13
Zambia	Min	405.3	2.98	2.73
	Average	434.5	3.34	3.08
	Max	463.8	3.70	3.43

Note that raw materials costs are not part of the analysis. (This is justified below, introducing a description of the price formation mechanisms in the non-ferrous metals industry.)

The final price of base metals is decided in international metal exchanges, most importantly the London Metals Exchange (LME), followed by the Shanghai Futures Exchange (SHFE) and the Commodity Exchange Inc. (COMEX) based in the United States [ECORYS, 2011; Nussir, 2012]. The final price paid for the finished product consists of the price determined on the metals exchange plus a regional price premium [ECORYS, 2011]. Cathode premiums used to reflect the quality, but they now tend to reflect the projected supply and demand situation and freight costs to customers.

The mines produce copper concentrates that are sold to smelters and refineries for their copper content. The income of the mines is a function of mainly the metal price determined on the exchange and the quality of the concentrate. Typically, once treatment charges (TCs) and refining charges (RCs) are subtracted, the smelter pays to the producer 96-97 % of the metal value contained in the concentrate [Nussir, 2012]. TCs and RCs, paid in USD, are usually fixed on an annual basis. The copper smelters and refineries require concentrate specifications that limit the amount of impurities allowable in the concentrate, otherwise financial penalties are levied. The general standard throughout the custom/toll smelting industry is a deduction of the percentage paid back to the mine for concentrates containing less than 30 % Cu [Wood Mackenzie, 2015b]. In 2013 the smelters paid for around 96.1 % of the copper value contained in concentrates [Wood Mackenzie, 2015b].

To conclude, raw material prices are set in the global market and usually passed on directly to customers. Therefore, they can be excluded from analysis that is solely linked to factors such as energy prices, labour costs and to a lesser extent to exchange rates.

The credits in the case of smelters are due to the sulphur by-products, while in the case of copper refineries they are due to nickel salts and cathode premiums. While many concentrates have sulphur contents in the range of 26-33 %, there is a significant number of concentrates outside this range. High sulphur content may have an impact on the energy balance of the smelter, affecting its operation. Nevertheless, the driving force behind producing sulphuric by-products (mainly sulphuric acid, but in some cases also gypsum and liquid SO_2) is environmental regulations rather than economic factors. Environmental legislation in Latin America has become more stringent in recent years. In general, the EU has high total sulphur collection efficiencies, reflecting the stringency of the environmental legislation (99.1 % in Finland and 99.5 % in Spain in 2013).

The global trends are that sulphur prices are decreasing. The acid selling price for individual smelters is almost entirely based on the region in which the smelter is located. An important factor affecting the price is when a smelter sells its acid on an intra-company transfer basis, for example for a metallurgical operation. Such arrangements typically occur in the Latin and North American regions. Table 43 includes the sulphuric acid prices reported by the smelters in the countries of interest.

Nickel originates in the anodes and in most copper refineries is an impurity that needs to be removed so as to ensure the quality of the copper cathode. It is recovered from the electrolyte as a by-product, usually as nickel sulphate. Nickel removal does not always offer the opportunity of a financial return, as it is an impure product that cannot be avoided. The Wood Mackenzie database assumes that on average the sulphate contains 22 % nickel and that the copper refinery obtains a net return equivalent to 60 % of the contained metal. This methodology is applied only to copper refineries that report production of nickel. The price assumed for 2012 was 1 815 EUR/$t_{nickel\ sulphate}$ and for 2013 1 493 EUR/$t_{nickel\ sulphate}$ [Wood Mackenzie, 2015a].

Cathode premiums, as mentioned earlier, are part of the revenue of the copper refineries. In some cases the premiums are not enough to cover the costs related to the supply and demand situation and therefore seem to be penalties to copper refineries that are distant from their markets, and long overland transport costs magnify this effect. Contrary to nickel sulphate prices, cathode premiums are reported directly from the copper refineries. They are included in the analysis, since disregarding them would distort the net costs of the copper industry. The average values for the copper refineries included in this study are shown in Table 43.

5.3 Zinc

Similarly to the copper industry, zinc smelters charge the treatment costs to the mines and pay back a percentage of the metal value contained in the concentrate. As a result, the breakdown of the costs for the zinc industry is similar to the one for copper.

Table 46: Prices of energy used in the zinc industry [Wood Mackenzie, 2015a]

			EU	CHN	KAZ	NAM	NOR	RUS
Electricity (EUR/MWh)	2012	Min	40.3	51.4				
		Average	59.2	59.8	19.7	20.4	40.8	52.9
		Max	91.0	72.7				
	2013	Min	39.2	50.3				
		Average	58.5	59.1	18.9	19.6	39.1	56.2
		Max	93.7	73.5				
Natural gas (EUR/MWh)	2012	Min	21.60					8.23
		Average	32.04	21.96				9.00
		Max	41.76					9.72
	2013	Min	20.88					9.00
		Average	31.68	17.64				9.72
		Max	46.80					10.80
Fuel oil (EUR/t)	2012	Min	591.56	434.65				
		Average	885.14	688.45	599.40		936.76	
		Max	1 140.75	942.25				
	2013	Min	532.34	602.36				
		Average	781.72	720.58	539.12		842.56	
		Max	1 014.23	838.79				
Coal (EUR/t)	2012	Average		73.75				
	2013	Average		56.47				
Coke (EUR/t)	2012	Min	127.10	102.78	109.05			89.44
		Average	184.37	132.12	118.47			105.92
		Max	241.64	161.62	127.88			122.39
	2013	Min	100.14	85.84	90.35			74.24
		Average	145.32	108.80	98.26			87.95
		Max	190.50	128.00	106.17			101.65
Sulphuric acid (EUR/t)	2012	Min	16.32	24.95				35.31
		Average	33.97	35.04	27.77		38.44	39.31
		Max	64.88	49.43				43.31
	2013	Min	7.30	0.38				27.86
		Average	26.61	8.43	23.04		29.82	32.26
		Max	53.16	12.72				36.67

Energy costs include electricity (the major energy source for electrolytic smelters), coke, natural gas and fuel oil. The EU zinc smelters use mainly natural gas and secondarily fuel oil, while Chinese smelters use mainly coke and Russian ones use coke and natural gas. Table 46 includes the average, minimum and maximum costs for the different types of energy. If only an average price is mentioned, it may mean that either there is only one smelter, or that the country has one price without variations, or there is only one smelter using this type of energy and therefore reporting a price for it.

Labour and other costs include, as for copper, labour, maintenance, consumables and other on-site costs, the latter being the general and administrative costs associated with the operation of the smelter site. Labour rates vary enormously among the different countries, with Germany having one of the highest rates and China one of the lowest in the world. During the last decade, there has been an increase in the labour costs of China, even if they are still lower than the average labour costs, and they start to be a reason for concern for the Chinese smelters [Wood Mackenzie, 2015c].

As it can be seen from Table 47, the countries with high labour rates (such as Norway) also have a high productivity due to the use of more automated plants requiring less labour and hence minimising overall labour costs. Conversely those with low labour rates have lower productivity. In the EU the highest productivity and labour costs are found in Germany, the Netherlands and Finland.

Table 47: Productivity and manpower costs in the zinc industry [Wood Mackenzie, 2015a]

		Productivity	**Hourly labour cost (EUR/h)**	
		(t Zn/man)	**2012**	**2013**
EU	Min	104.6	5.01	5.29
	Average	341.4	29.51	32.05
	Max	564.1	55.55	55.91
China	Min	30.0	1.61	1.65
	Average	84.9	2.12	2.29
	Max	143.6	2.85	2.92
Kazakhstan	Min	98.6		
	Average	122.8	7.08	7.12
	Max	147.1		
Namibia	Min			
	Average	263.6	12.75	10.95
	Max			
Norway	Min			
	Average	535.3	58.44	55.29
	Max			
Russia	Min	69.2	5.61	5.86
	Average	80.6	6.60	7.04
	Max	92.1	7.58	8.22

In the case of zinc smelters, the credit is attributed to sales of sulphur-based compounds, usually sulphuric acid, but also sulphur, liquid SO_2 or even gypsum, that are generated from the smelter's sulphur recovery system. As in the case of copper, the driving force for isolating sulphur compounds in the zinc industry is environmental regulations. Table 46 includes only the sulphuric acid prices reported by smelters in the countries of interest, as sulphuric acid is the most common by-product.

D.6 Consumption of energy, raw materials and other resources

6.1 Aluminium

Table 48 shows consumptions of energy and raw materials per tonne of product. Facilities that buy the prebaked anode in the market substitute the anode manufacturing costs of Table 48 by its price (prices in Table 41).

Electricity and alumina prices (Table 40 and Table 41), together with their consumptions (in Table 48), are the most relevant components of total production costs, provided and discussed in Section 7.1.

Table 48: Energy and raw materials consumption in the anode-manufacturing aluminium smelters [EAA, 2013; Pawlek, 2014; Lin and Xu, 2015]

		Anode manufacturing			Aluminium smelter		
Consumption of		Coke+ pitch	NG	Electricity	Alumina	Gross anode	Electricity
		t/t anode	GJ/t anode	MWh/t anode	t/t liquid Al	t/t liquid Al	MWh/t liquid Al
EU	Min					0.495	13.2
	Average	0.869	2.76	0.108	1.920	0.538	13.9
	Max					0.580	15.1
CHN	Min				1.936	0.450	12.0
	Average	0.869	3.09	0.114	1.942	0.576	13.9
	Max				1.949	0.650	14.4
ISL	Min						13.2
	Average	0.869			1.920	0.51	13.8
	Max						15
KAZ	Average	0.869	3.09	0.114	1920	0.550	13.5
NOR	Min					0.493	12.9
	Average	0.869	2.76	0.108	1.920	0.507	14.7
	Max					0.530	17.9
RUS	Min				1.920	0.479	14.8
	Average	0.869	3.09	0.114	1.930	0.559	15.3
	Max				1.935	0.622	16.0

The Chinese average value of electricity consumption comes from [Lin and Xu, 2015], the rest of the values are estimated from information in [Pawlek, 2014].

Table 49: Energy and raw materials consumption in the casting house [EAA, 2013]

	Liquid aluminium	Scrap	Coal	Fuel oil	NG	Electricit y
	t/t cast Al	t/t cast Al	GJ/t cast Al	GJ/t cast Al	GJ/t cast At	MWh/t cast Al
EU, Iceland, Norway	0.875	0.125	0	0.234	1.349	0.098
China, Kazakhstan, Russia	0.958	0.042	0.024	0.145	0.761	0.068

6.2 Copper

Table 50 shows raw materials and energy consumptions of smelters per tonne of copper anode. This table provides the aggregated electricity and total energy consumption (including electricity). Net energy consumption is the total energy consumed in the process of extracting copper from concentrates to produce anodes, minus the credit for power or steam generated. This net energy includes the energy consumed in associated processes such as oxygen and acid plants, regardless of whether the smelter directly operates these processes or not.

Table 50: Raw materials and energy consumption in copper smelters in 2012 and 2013

Consumption of		Concentrates t/t Cu_a		Electricity MWh/t Cu_a		Total net energy GJ/t Cu_a	
		2012	2013	2012	2013	2012	2013
EU	Min	2.98	2.64	0.62	0.58	1.63	1.66
	Average	3.50	3.43	1.14	1.10	9.97	9.57
	Max	4.06	3.92	2.36	2.09	15.44	15.25
Chile	Min	3.00	2.72	0.80	0.86	8.08	8.00
	Average	3.68	3.60	1.20	1.20	9.92	9.44
	Max	4.06	3.93	1.85	1.81	11.95	11.17
China	Min	2.50	2.59	0.82	0.71	5.14	5.44
	Average	4.15	4.05	1.22	1.9	10.33	9.92
	Max	5.03	5.09	1.66	1.59	16.05	15.25
Peru	Average	3.94	3.89	1.10	1.11	8.73	8.57
Zambia	Min	2.91	3.43	1.16	1.38	8.46	8.52
	Average	3.30	3.53	1.30	1.39	10.30	11.22
	Max	3.59	3.67	1.37	1.40	12.63	15.08

Besides electricity, the majority of copper smelters in the EU and Chile consume natural gas and fuel oil, and to a much lesser extent coal and coke. On the other hand, in the case of China, Peru and Zambia the energy mix includes mainly coal and fuel oil.

Table 51: Raw materials and energy consumption in copper refineries in 2012 and 2013

Consumption of		Anodes t/t Cu_c		Electricity MWh/t Cu_c		Total net energy (37) GJ/t Cu_c	
		2012	2013	2012	2013	2012	2013
EU	Min	1.11	1.08	0.31	0.31	1.49	1.49
	Average	1.19	1.17	0.40	0.40	2.45	2.43
	Max	1.25	1.27	0.62	0.62	3.20	3.20
Chile	Min	1.07	1.07	0.29	0.29	1.69	1.69
	Average	1.17	1.21	0.35	0.35	2.63	2.52
	Max	1.22	1.36	0.44	0.41	3.86	3.52
China	Min	1.16	1.17	0.31	0.32	2.19	2.04
	Average	1.20	1.20	0.35	0.35	3.22	3.08
	Max	1.24	1.23	0.40	0.41	4.57	4.55
Peru	Average	1.21	1.22	0.41	0.30	1.79	1.09
Zambia	Min	1.20	1.20	0.41	0.41	2.30	2.30
	Average	1.22	1.22	0.52	0.52	2.83	2.83
	Max	1.23	1.23	0.64	0.64	3.37	3.37

Table 51 includes raw materials and energy consumptions of copper refineries per tonne of copper cathode. The net energy consumption mentioned in this table refers to the

(37) Total energy consumption includes electricity, steam and other fuels that may be consumed in each facility according to the Wood Mackenzie database [Wood Mackenzie, 2015a].

energy consumed in the electrolytic refining process, including on-site anode casting where appropriate. It also includes waste heat steam used for heating being supplied by an associated smelter, but waste heat from an integrated anode casting plant is not taken into consideration.

The major source of energy in electrolytic copper refineries is electrical energy, most of which is used for copper deposition in the tankhouse. The theoretical direct current consumption of the process is determined by Faraday's law for copper, the cell voltage required for deposition, and current efficiency. Typical alternating current consumption is about 320 kWh/t cathode. Differences in cell geometry, current efficiency and other characteristics of copper refineries can cause variations from the theoretical consumption.

6.3 Zinc

Table 52 includes raw material and energy consumptions of zinc smelters per tonne of zinc produced. The energy mix in zinc smelters is very diverse, having only electricity consumption in common. In the EU most smelters use natural gas or fuel oil, only in Bulgaria and Poland do smelters use coke, but one of them is based on imperial smelting furnace (ISF) for which coke is the main fuel. In China, Kazakhstan and Russia the percentage of coke in the energy mix is much higher. Table 52 shows only electricity in detail and total energy consumption. Net energy consumption is based on total energy consumed in the process of extracting zinc from raw materials, together with a credit for power generated inside the facility.

Table 52: Raw materials and energy consumption in zinc smelters in 2012 and 2013

Consumption of		Concentrates t/t Zn		Electricity MWh/t Zn		Total net energy GJ/t Zn	
		2012	2013	2012	2013	2012	2013
EU	Min	1.75	1.76	1.10	1.10	13.97	14.18
	Average	2.01	1.99	3.77	3.76	19.30	19.98
	Max	2.63	2.63	4.33	4.32	47.89	49.89
China	Min	1.87	19.92	3.84	3.80	15.12	14.88
	Average	2.56	2.54	4.14	4.06	23.70	21.94
	Max	5.26	5.26	4.30	4.30	29.12	29.12
Kazakhstan	Min	2.00	1.97	4.50	4.47	28.92	28.92
	Average	2.38	2.36	4.61	4.60	37.90	37.85
	Max	2.76	2.74	4.73	4.73	46.87	46.78
Namibia	Average	11.50	11.29	4.60	4.60	16.56	16.59
Norway	Average	1.84	1.84	4.41	4.50	15.99	16.31
Russia	Min		2.10	4.40	4.40	30.67	30.67
	Average	2.10	2.11	4.47	4.44	31.78	31.35
	Max		2.12	4.55	4.49	32.89	32.03

D.7 Costs

In a similar way to the rest of industries treated in this project (iron and steel, cement and chemicals), in order to estimate production costs, we combine in this final section all consumptions and prices already described. With this aim, for the three non-ferrous metals, we provide a detailed breakdown of the production costs in bar graphics that show the evolution of costs for two years. Other additional figures (Figure 91, Figure 93, Figure 95 and Figure 98) show the variability observed in the population of facilities in each country. In these last figures, each curve represents a component of the costs, and the countries are ranked according to their increasing average costs. The vertical lines join the minimum and maximum costs estimated in each country.

Following the same approach as for the rest of the industries we exclude the capital costs (depreciation) and profit from the production costs.

7.1 Aluminium

Table 53 details the information behind Figure 90 that summarises the average primary aluminium production costs in 2012 and 2013. At the time of writing (June 2015) the latest published aluminium price (1 627 EUR/t) is quite close to the average value (1 620 EUR/t) of the last 10 years (from 2005 to 2014) [Indexmundi, 2015]. However, during 2012 and 2013 the average aluminium price was 1 572 EUR/t and 1 391 EUR/t, respectively, while the average of the estimated production costs of the EU industry those years was 1 411 EUR/t and 1 295 EUR/t, respectively.

Regarding the low aluminium production costs in Kazakhstan, it can be said that this country (with only one smelter of 0.24 Mt Al in operation since 2010) together with Iceland has one of the lowest electricity prices; this fact, together with its low alumina price (from its own refinery) and low labour cost, produces the lowest production costs. In 2011 this smelter/country exported 40 % of its production to Russia, and the remaining 60 % was bought by the Swiss-based commodities trader Glencore [Pawlek, 2014].

On the other extreme there are the Chinese smelters. Out of the studied countries, China is the one in which the high energy costs contribute the most to the total aluminium production costs. Moreover, although the average costs under the 'labour and others' heading is much lower than the values in the EU, it shows a huge variability (Figure 91). Once that variability is transferred to the total costs, it places the least competitive Chinese producers far from the rest of the competitors. Note that, although China's aluminium production is almost half of global production (46.6 %, Figure 80), it hardly exports to the EU (Figure 81). In fact, Chinese smelters populate the fourth and third quartile of the cost curve [Djukanovic, 2012] despite the fact that they have some of the most energy-efficient smelters, and the number of smelters in construction is higher than the number of smelters in the EU.

The decrease of production costs in the EU from 2012 to 2013 is mainly due to the decrease of electricity and alumina prices. In those two years, the wholesale market electricity price and alumina price fell around 13 % and 8 %, respectively. In the EU in 2013 the electricity and alumina prices alone accounted for around 40 % of total aluminium production costs each.

Table 53: Breakdown of the total production costs per tonne of cast aluminium in 2012 and 2013

		EU	China	Iceland	Kazakhstan	Norway	Russia
Electricity	2012	523.5	669.9	246.0	282	371	320.1
	2013	467	718.8	239.8	265	399.4	336.1
NG, coke, coal	2012	55	46	10	37	37	31
	2013	49	49	9	40	32	33
Raw materials	2012	657	690	846	390	702	640
	2013	604	643	756	362	644.5	595
Labour and others	2012	179.6	78.2	101.8	15.2	139.1	22.0
	2013	177.9	86.6	97.8	15.0	133.5	24.2
Total	**2012**	1 415	1 484	1 203	725	1 250	1 013
	2013	1 298	1 497	1 102	682	1 209	988

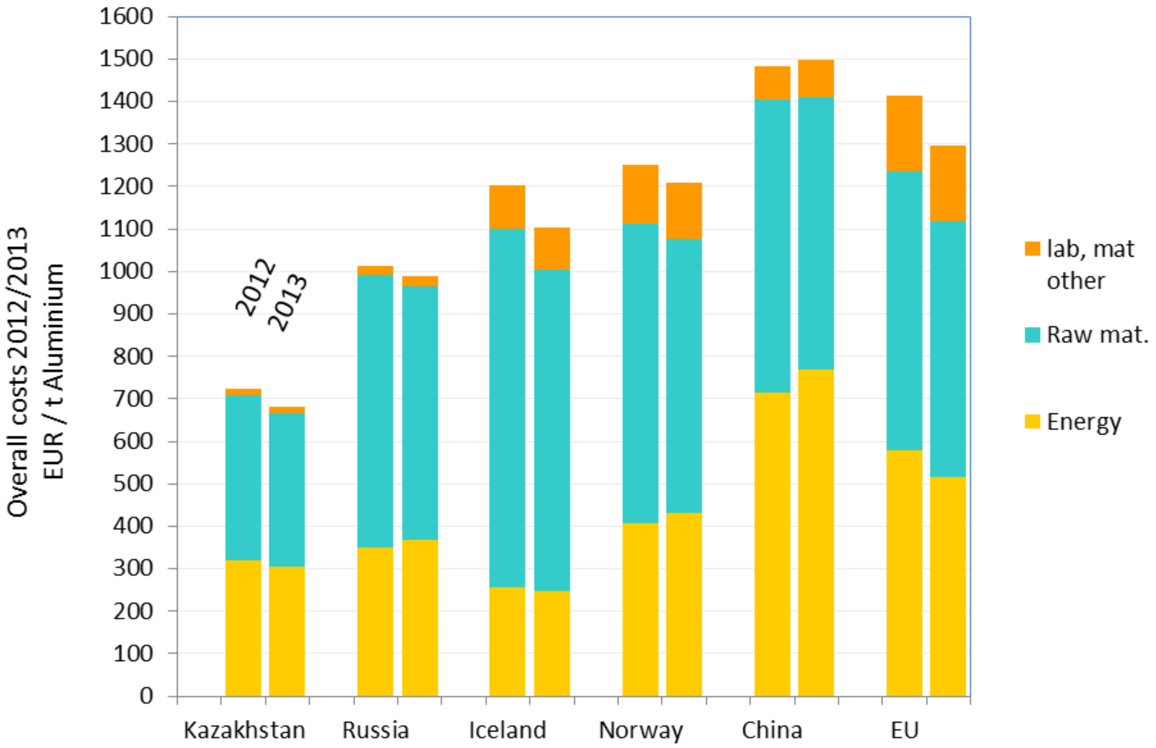


Figure 90: Summary of total production costs per tonne of cast aluminium in 2012 and 2013

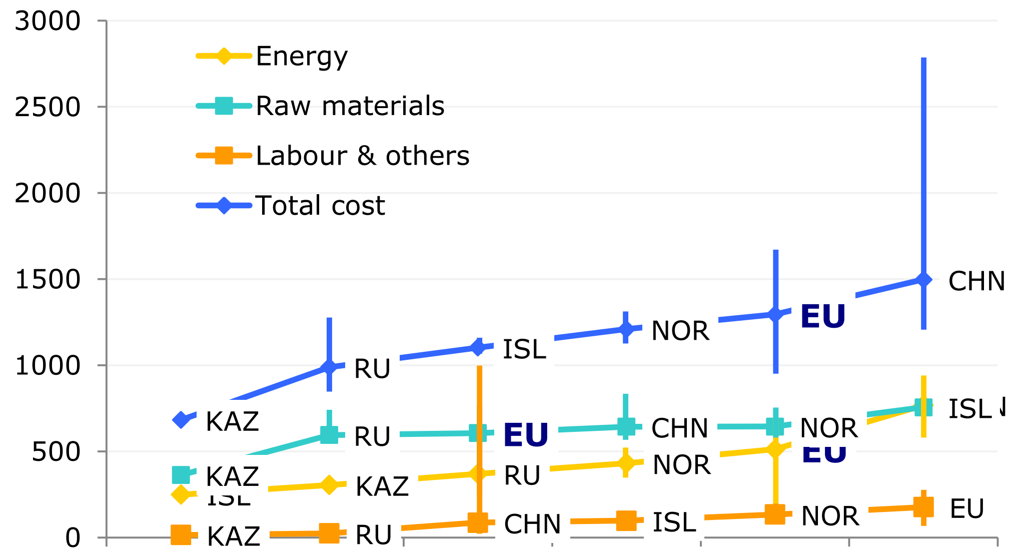


Figure 91: Average aluminium cost curve in 2013 and intervals encompassing the maximum and minimum estimated production costs

The lowest value of the production costs in the EU is well below the Icelandic and Norwegian production costs; however, the three lowest values in the EU are due to the low electricity prices of the bilateral contracts. If we excluded those contracts from the estimations, there would hardly be any overlap between the production costs in Iceland and in the EU. Also, the average value of the production costs in the EU would increase by 3.4 % (from 1 295 EUR/t to 1 339 EUR/t).

7.2 Copper

Table 54 includes the information depicted in Figure 92, referring to the production costs of copper smelters.

Table 54: Breakdown of the total production costs per tonne of copper anode in 2012 and 2013

		EU	Chile	China	Peru	Zambia
Energy	2012	114.6	216.9	92.1	163.5	100.2
	2013	103.0	200.0	91.6	151.4	109.3
Labour and others	2012	229.0	449.5	79.8	353.1	148.4
	2013	231.2	401.5	83.6	278.0	138.9
Credits	2012	− 80.9	− 290.4	− 79.3	− 317.1	− 238.1
	2013	− 55.6	− 184.3	− 29.2	− 188.3	− 241.5
Total	**2012**	262.6	376.0	92.6	199.5	10.5
	2013	278.6	417.2	146.0	274.1	6.5

It is interesting to note that energy costs in most cases are about 30-35 % and labour and other costs 65-70 % of the total expenses of the smelters. These figures are in accordance with the cost structure suggested in [ECORYS, 2011]. The only exception is China where labour costs are still much lower than in the rest of the countries. Concerning the credits, the acid prices have been decreasing since 2008, when a global spike in the acid price was observed [Wood Mackenzie, 2015b]. The prices of sulphuric acid in Latin America are still high, as the majority of acid is needed in the metallurgical industry. In 2013 the country with the highest price of sulphuric acid was Zambia because of high transport costs and long distances as well as the fact that oxide ores are treated, with an average price of 157.7 USD/t [Wood Mackenzie, 2015b].

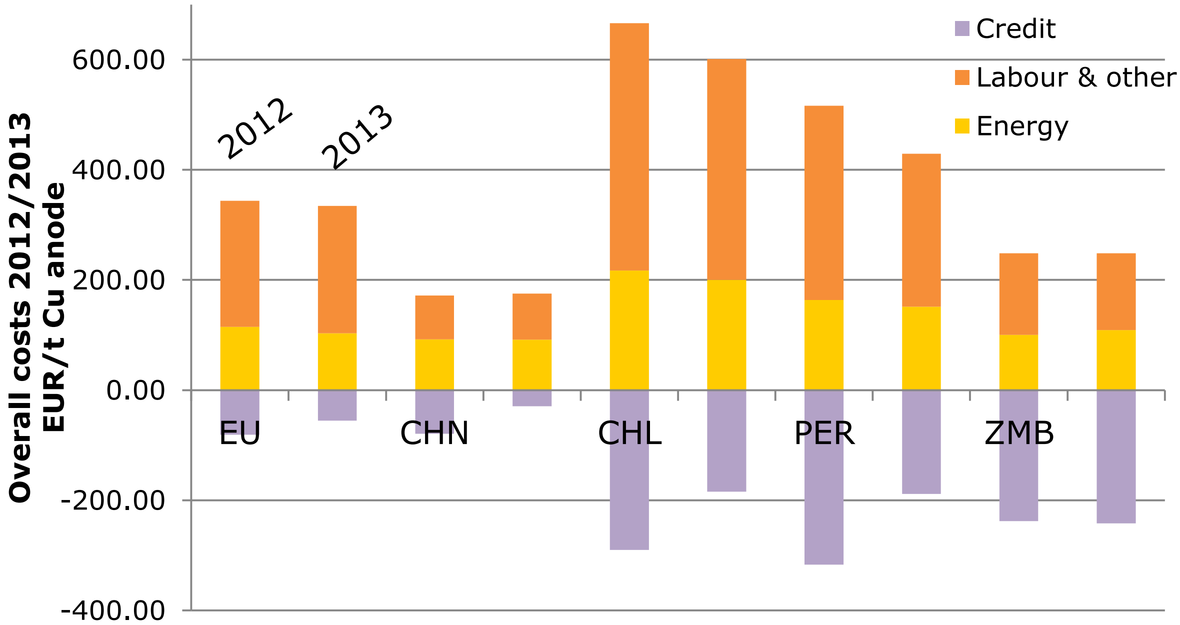


Figure 92: Summary of total production costs of copper smelters in 2012 and 2013

The total expenses in 2013 were lower than the expenses in 2012 thanks mainly to lower electricity prices in 2013. But as the credits were also lower in 2013 than in 2012, the total production costs increased in all countries except Zambia.

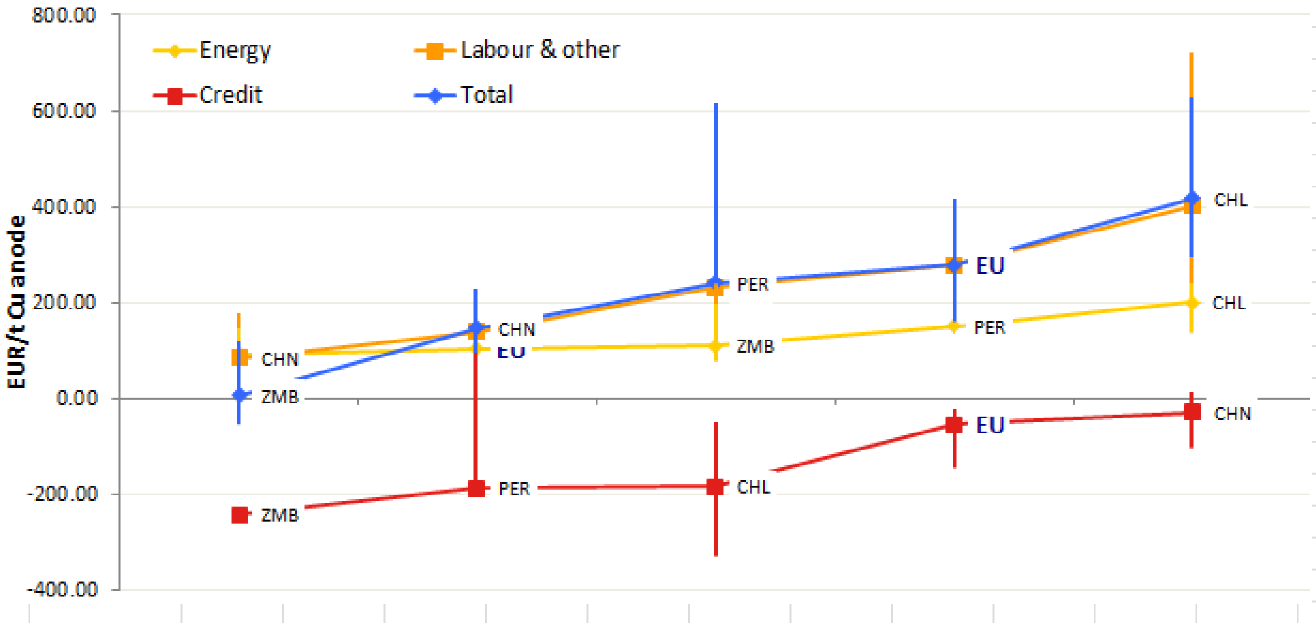


Figure 93: Average copper anode cost curve in 2013 and intervals encompassing the maximum and minimum estimated production costs

As it can be seen in Figure 93, the lowest value in the EU is lower than the Chinese average costs. Chile, although representing the majority of EU imports of final copper products, has much higher production costs due to high energy prices as well as high labour costs.

Table 55, Figure 94 and Figure 95 show the same analysis as above but for copper refineries. Once more it is clear that the labour costs in the case of China are much lower compared to the rest of the countries. Energy costs in copper refineries represent 30-35 % of the total expenses, except for China, where energy represents 52 % of the expenses. Copper refineries are consuming less electricity than smelters and therefore, the decrease in electricity prices does not influence the total expenses as much. On the other hand, due to the differences in the cathode premiums, for Chile, Peru and Zambia, the credits appear as penalties, increasing the total production costs.

Table 55: Breakdown of the total production costs per tonne of copper cathodes in 2012 and 2013

		EU	**Chile**	**China**	**Peru**	**Zambia**
Energy	2012	29.2	61.6	31.6	42.8	28.6
	2013	27.0	64.8	30.1	26.0	27.7
Labour and others	2012	54.3	150.0	29.4	104.0	53.9
	2013	55.2	175.6	31.4	109.4	49.7
Credit	2012	– 43.3	5.6	– 42.8	– 12.8	29.5
	2013	– 37.1	5.6	– 38.5	55.7	28.9
Total	**2012**	40.2	217.2	18.2	134.0	112.1
	2013	45.1	246.0	23.1	191.2	106.3

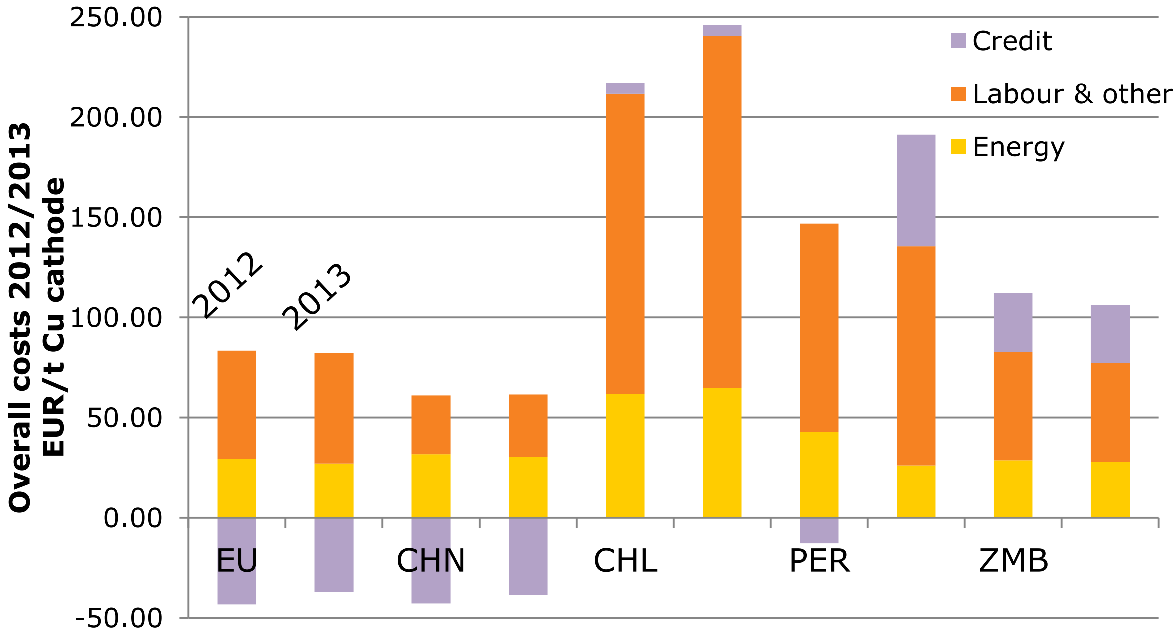


Figure 94: Summary of total refined copper costs in 2012 and 2013

In the case of copper refineries, the EU copper industry has much lower production costs than the countries from where most of the imports of copper cathodes are originating. Due to high automation and high cathode premiums, the EU average is comparable to the average costs in China.

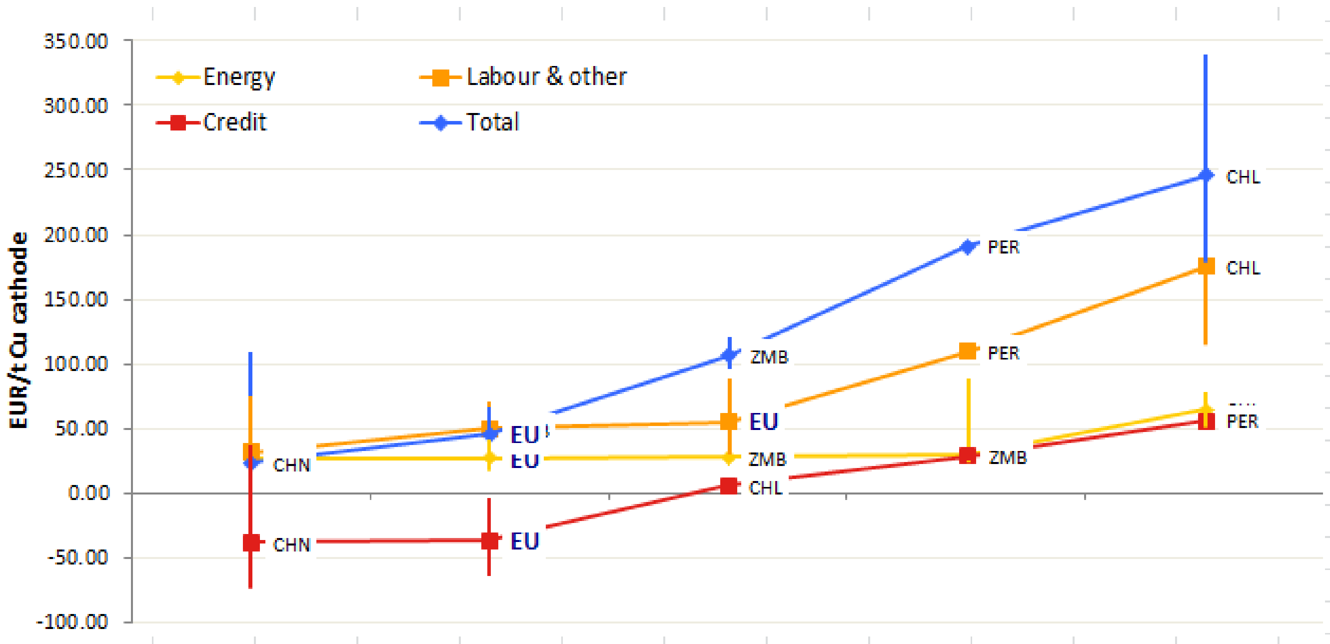


Figure 95: Average copper cathode cost curve in 2013 and intervals encompassing the maximum and minimum estimated production costs

Concerning the price of copper in the LME, the average international prices of copper Grade A was 6 244 EUR/t in 2012 and 5 520 EUR/t in 2013.

As explained in Section 5.2, the cost of copper concentrates, which smelting and refining companies pay to mining companies, is the LME copper cathode price after deducting treatment and refining costs. Figure 96 shows the average treatment and refining charges in the copper industry for 2012 and 2013. TCs are usually expressed per tonne of concentrate treated, while RCs are expressed per tonne of cathode. In order to unify the terms of reference, the average conversion of anodes to cathodes per country (or region in the case of EU) is used.

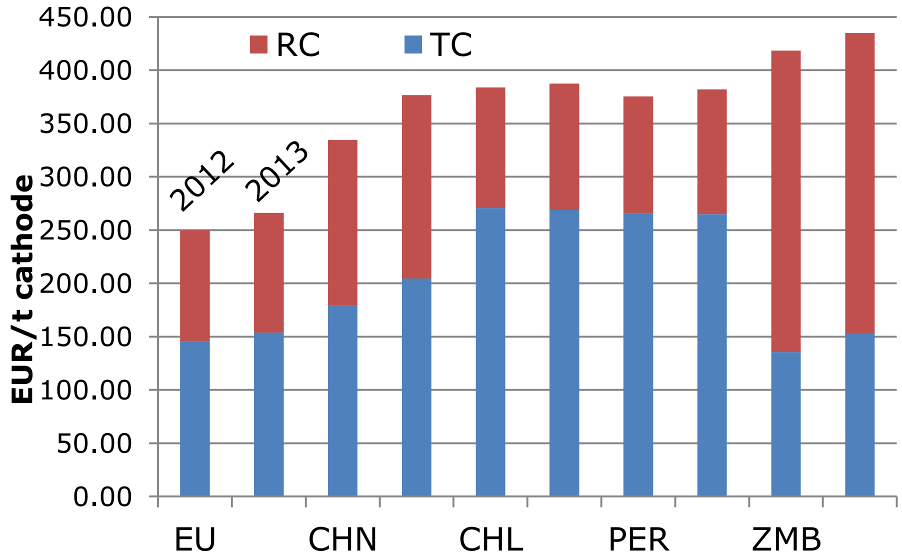


Figure 96: Average treatment charges (TC) and refining charges (RC) in the copper industry for 2012 and 2013

In order to compose a market price of copper from the countries under study, we estimate the price of the concentrate that should be aggregated to the TC/TR prices to get the final price in the market. These estimations, provided in Table 56, are based on Eurostat trade data [Eurostat, 2015a]. However, as explained in Section 5.2, the concentrates prices are directly linked to the metal prices in the market and are directly passed on from the final buyer to the mine, even when in some cases the copper producer is involved.

Table 56: Copper concentrates prices and treatment/refining charges (TC/RC) for 2012 and 2013

(EUR/t Cu cathode)	2012			2013		
	Price Cu concentrates ([38])	TC/RC	Total	Price Cu concentrates	TC/RC	Total
EU	5 212.2	249.9	5 462.1	4 663.7	266.2	4 929.9
Chile	3 912.3	383.9	4 296.2	4 132.9	387.5	4 520.4
China	4 779.8	334.5	5 114.3	4 405.0	376.6	4 781.6
Peru	5 325.8	375.3	5 701.1	4 865.4	382.1	5 247.5
Zambia	4 348.5	418.4	4 766.9	4 218.0	435.0	4 653.0

7.3 Zinc

The costs for the different components in the case of zinc smelters are summarised in Table 57 and Figure 97. Once more the difference in labour costs between China and the other countries is obvious. For the countries of interest in the zinc industry, the sulphuric by-products offer similar credits, without the differences that were noticed in the case of copper in Zambia.

Table 57: Breakdown of the total production costs per tonne of slab zinc in 2012 and 2013

		EU	**China**	**Kazakhstan**	**Namibia**	**Norway**	**Russia**
Energy	2012	222.0	309.2	190.8	93.8	182.4	288.4
	2013	226.3	295.7	172.5	80.4	178.1	293.3
Labour and others	2012	259.9	163.3	289.4	433.9	327.3	386.1
	2013	255.3	173.7	279.9	391.4	320.7	411.0
Credits	2012	− 44.9	− 32.8	− 39.3		− 28.0	− 64.4
	2013	− 35.1	− 12.7	− 31.6		− 24.7	− 51.6
Total	**2012**	436.9	439.7	441.0	527.7	481.7	610.1
	2013	446.5	456.7	420.7	471.7	474.1	652.7

([38]) This price is expressed per tonne of copper cathode and not per tonne of concentrate.

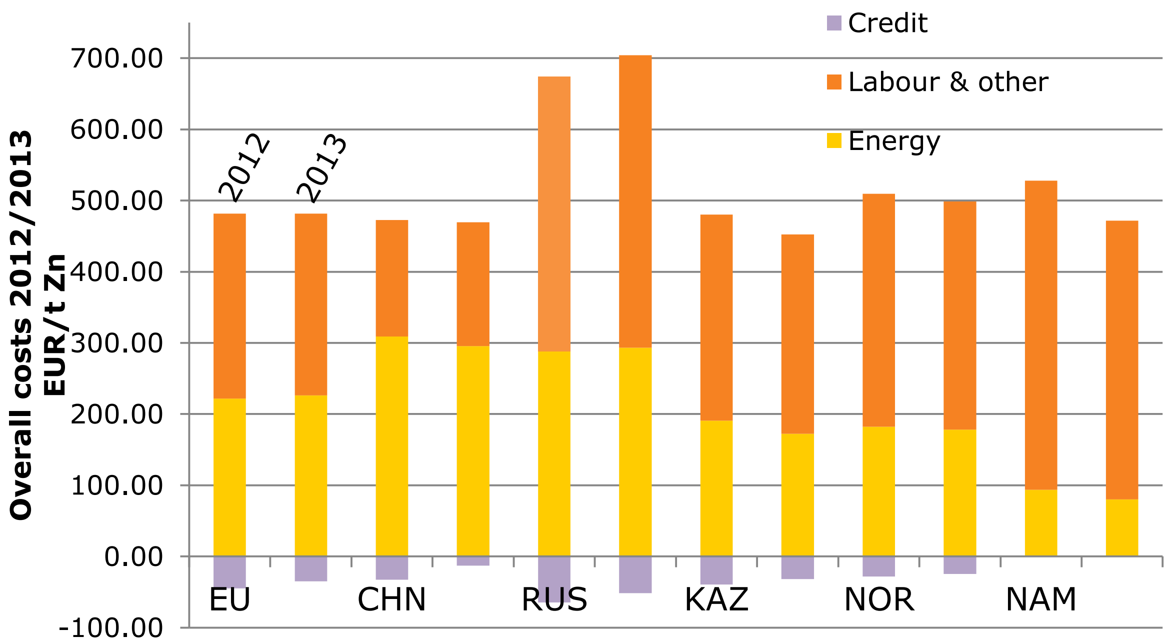


Figure 97: Summary of total zinc industry costs in 2012 and 2013

Figure 98 shows the specific costs in each country. There are no remarkable differences among the different countries, except for Russia. However, note that the highest value in the EU is even higher than any of the Russian values. The great variation of the values in the EU can be attributed to large differences in electricity prices in the Member States, as can be seen in Figure 98.

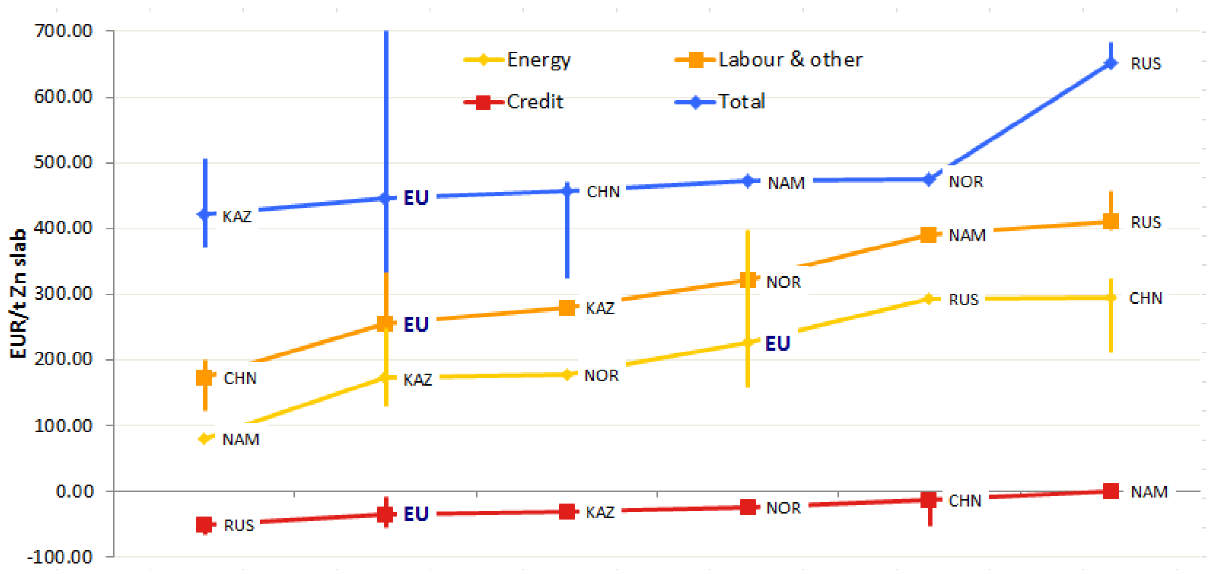


Figure 98: Average zinc cost curve in 2013 and intervals encompassing the maximum and minimum estimated production costs

The average price for zinc settlement was 1 438.5 EUR/t in 2012 and 1 527.6 EUR/t in 2013 [Inees, 2015]. Following a similar methodology as in the case of copper, the price of zinc concentrates is estimated using Eurostat trade data [Eurostat, 2015a]. The zinc price for the countries outside the EU is estimated according to their exporting prices to the EU.

Table 58: Zinc concentrates prices and treatment charges (TC) for 2012 and 2013

(EUR/t Zn)	2012			2013		
	Price Zn concentrates (39)	TC	Total	Price Zn concentrates	TC	Total
EU	992.5	281.3	1 273.8	992.2	291.0	1 283.2
China	1 222.1	237.8	1 459.9	1 278.4	373.4	1 651.8
Kazakhstan	1 190.7	270.0	1 460.7	1 189.6	310.7	1 500.3
Namibia	5 868.0	333.5		5 076.9	258.6	
Norway	980.3	273.4	1 253.7	1 111.4	289.1	1 400.5
Russia	1 097.0	254.8	1 351.8	1 115.7	300.7	1 416.4

Table 58 shows the estimated price for concentrates weighted according to zinc production and treatment charges reported by the industry. The zinc price for Namibia is an outlier because concentrates in that country are of much lower quality than in the rest of the countries. For example, concentrates in Namibia have about 10 % zinc, while concentrates in Norway have 55 % and in Germany 51 %.

(39) This price is expressed per tonne of zinc and not per tonne of concentrate.

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