Institute of Electrotechnology

The Scope for Electricity & Carbon Saving in the EU through the use of EPM Technologies

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Scope of the Project

Electromagnetic processing of materials (EPM) provides significant opportunities for saving primary energy and reducing carbon emissions in industrial thermal processes. The use of electricity for industrial thermal processes has a current market share of around 10% in Europe and is divided in numerous different applications and industrial branches, where today the share between fossil fuel and electricity used as the end energy carrier is absolute different. All applications and processes play a different role and offer different potentials in terms of saving of primary energy and reducing of greenhouse gas emission. Potentially, electricity can replace up to 100% of other energy carriers currently used for process heat. As the average primary energy factor (PEF) gradually decreases from 2.5 currently, to 1 for a 100% renewable electricity system, the benefits of EPM will gradually increase. The CO_2-emission factor will decrease as well which means a decrease in greenhouse gas emissions. Moreover, as the electricity system is decarbonising rapidly, EPM technologies will increase with time. A very important background and basic for this analysis is the forecast of the future energy supply.

The paper demonstrates the features, benefits and advantages of processes and technologies for electromagnetic processing of materials (EPM). For the time horizon from now to the year 2050 a transition scenario is developed and described. In this scenario the industrial processes are gradually switched from the actual situation to a situation with 100% electrically operated industrial processes. The scenario will take into account both the most energy intensive industrial thermal processes, which could be replaced by electrothermal technologies and offer obviously the biggest future potential in terms of saving of primary energy and reducing of carbon emissions but also lower energy intensive heating processes, which are used in many different industrial branches and require a more detailed investigation.

Executive Summary

The work in hand makes clear that a switching of fuel operated industrial processes to electro-thermal processes offers big potentials for saving of primary energy and CO_2-emission.

A very important background and basic for this analysis is the forecast of the future energy supply in Europe. In this investigation the main focus is set on the development of the primary energy factor (PEF) and CO_2-emission factor which is presented for each year till to 2050. It can be expected that the primary energy factor will decrease from currently 2.5 to 1 due to the increasing supply by renewable energies. The CO_2-emission factor will decrease as well, which means a decrease in greenhouse gas emissions.

In this work the savings of CO_2-emissions are calculated for a variety of different energy-intensive industrial processes. To calculate the savings three different switching scenarios are compared.

- The first is the reference scenario, which implies no switching to electrical processes.
- The second scenario, called linear scenario, assumes a linear increase of electrical processes to 100% in the year 2050.
- The shock scenario is the third one and implies an increase from the current situation to 100% between the years 2020 and 2025.

In 2009 the overall energy consumption of the European industry reached a value of 3,133,762 GWh. Altogether five energy intensive industrial branches have been analysed with the help of case studies. These five industry sectors ordered by the final energy demand in 2009 are the chemical industry with 585,896 GWh, the iron and steel industry with 514,848 GWh, the glass, pottery and building material industry with 424,832 GWh, the paper and printing industry with 384,116 GWh and the non-ferrous metal industry with 103,681 GWh (compare with Fig. 5). These selected five industry sectors cover about 70 % of the overall energy consumption of the European industry.

Table 1 summarizes the share of the calculated final energy demand on the overall final energy demand of the five different branches. The table gives an overview how much the case studies cover the overall energy demand.

Table 2 summarizes the savings respectively additional amounts of final energy, primary energy and CO_2-emission that can be achieved.

Branch	Industry sector	Calculated final energy demand in 2010	Final energy demand of the branch	Share
Chemical	Plastic	**110,500**		
Sum		**110,500**	**585,896**	**19 %**
Iron & steel	Steel	**434,923**		
	Grey iron	**10,972**		
Sum		**445,904**	**514,848**	**87 %**
Glass, pottery & building materials	Glass	**55,500**		
	Roof tile	**10,493**		
	Brick	**28,976**		
	Cement	**289,907**		
	Lime	**36,400**		
Sum		**421,275**	**424,832**	**99 %**
Paper & printing	Paper	**200,299**		
Sum		**200,299**	**384,116**	**52 %**
NF metals	Aluminum	**2,774**		
Sum		**2,774**	**103,681**	**3 %**

Table 1: Share of the calculated final energy demands on the overall energy demand of the five different branches.

Branch	Industry sector	Saving potentials for using the linear scenario			Saving potentials for using the shock scenario		
		Final energy	Primary energy	CO_2-emission	Final energy	Primary energy	CO_2-emission
		GWh	PJ	Million tons	GWh	PJ	Million tons
Chemical	Plastic	0	-1,245.8*	102.6	0	-1,786.9	138.5
Iron & steel	Steel	1,298,039.8	5,678.5	1,469.6	1,804,591.2	7,852.2	2,039.9
	Grey iron	53,833	135.6	48.1	74,841	184.5	66.6
Glass, pottery & building materials	Glass	0	-1,258.3	128.9	0	-1,806.0	175.0
	Roof tile	0	-278.0	19.4	0	-398.7	26.0
	Brick	0	-779.8	55.0	0	-1,118.1	73.9
	Cement	0	-7,181.5	1,603.5	0	-10,311.7	2,204.6
	Lime	0	-1,047.8	150.2	0	-1,502.4	205.4
Paper & printing	Paper	0	-3,814.7	374.4	0	-5,469.7	508.1
Non-ferrous metals	Aluminum	32,136.7	104.9	13.3	44,677.9	144.8	18.3
Sum		1,384,009.5	-9,686.9	3,965.0	1,924,110.8	-14,212	5,456.3

Table 2: Savings of final energy, primary energy and CO_2-emission for the two the different industry sectors for both switching scenarios (* Negative numbers imply an additional effort).

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1. Introduction

The aim of this work is the formulation of a position report that demonstrates the benefits and advantages of processes and technologies for electromagnetic processing of materials (EPM) in Europe (EU-27). For the time horizon from now to the year 2050 a transition scenario is developed. In this scenario the industrial processes are gradually switched from the actual situation to a situation with 100% electrically operated industrial processes. The scenario will take into account both the most energy intensive industrial thermal processes, which could be replaced by electro-thermal technologies and offer obviously the biggest future potential in terms of saving of primary energy and reducing of carbon emissions but also lower energy intensive heating processes, which are used in many different industrial branches and require a more detailed investigation.

Very important for this analysis is the forecast of the future energy supply in Europe. In this work the main focus is set on the development of the primary energy factor and CO_2-emission factor which will be presented for every year up to 2050. It can be expected that the primary energy factor will decrease from 2.5 currently to 1 due to the increasing supply by renewable energies. The CO_2-emission factor will decrease as well which means a decrease in greenhouse gas emissions. In this work the savings of CO_2-emissions will be calculated for a variety of different energy-intensive industrial processes. To calculate the savings three different switching scenarios are compared. The first is the reference scenario, which implies no switching to electrical processes. The second scenario, called linear scenario, assumes a linear increase of electrical processes to 100% in the year 2050. The shock scenario is the third one and implies an increase from the current situation to 100% between the years 2020 and 2025.

2. Primary energy factor & CO_2 emission factor

For the evaluation of the advantages of the energy switching it is important to know who much primary energy and CO_2 –emissions can be saved with this strategy. For that it is important to know the primary energy factor and the CO_2 emission factor for each energy carrier.

The primary energy factor and the CO_2-emission factor for fossil fuels have been investigated in different studies[1]. The factors used in this work are listed in Table 3.

	Primary energy factor	CO_2 –emission factor [g/kWh]
Hard coal	1.071811361	406
Coke	1.114827202	473
Lignite	1.038421599	413
Petroleum products	1.095290252	301
Natural gas	1.072961373	227

Table 3: Primary energy factors and CO_2-emission factors for different fossil energy carriers.

The factors of primary energy and CO_2 –emissions for electrical power depend on the composition of the energy mix in Europe. For that the forecast of the energy supply in Europe is a crucial factor of this work. With an increasing share of renewable energy carrier on the energy mix in Europe both factors will decrease. The development of the primary energy factor and the CO_2 -emission factor from now to the year 2050 will be used to calculate the possible savings of primary energy and CO_2 – emissions in Europe. The primary energy factor is calculated by dividing the development of the gross electricity generation by the primary energy used for the gross electricity generation. The estimated development of the gross electricity production in Europe is pictured in Fig. 1 and the estimated primary energy that is used for this gross

[1] **E. Baake, U. Jörn, A. Mühlbauer. 1996.** *Energiebedarf und CO2-Emission industrieller Prozeßwärmeverfahren.* Essen : VULKAN VERLAG, 1996. 3-8027-2912-9.

energy generation can be seen in Fig. 2. In Fig. 3 the development of the calculated primary energy factor is shown.

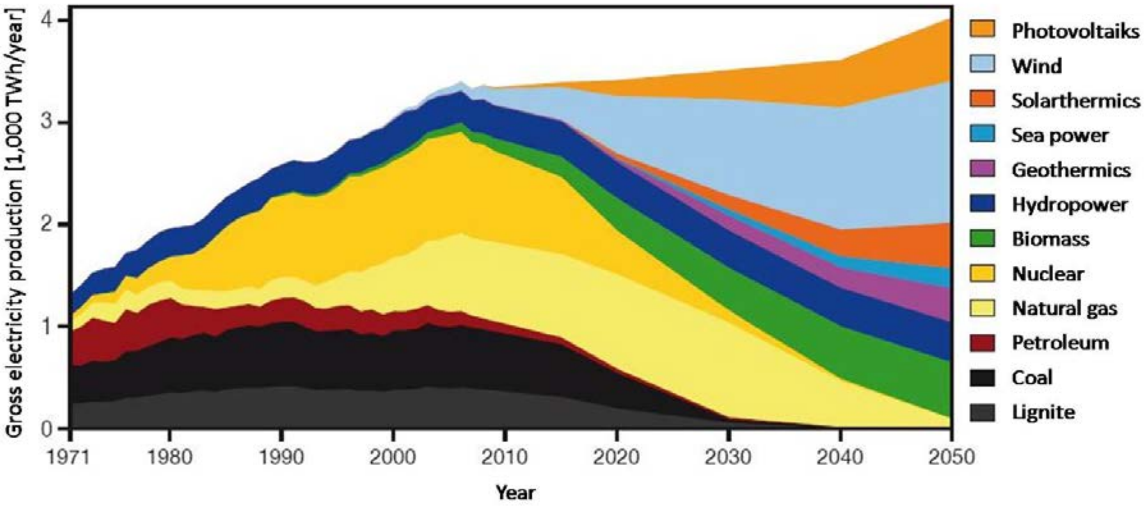

Fig. 1: Estimated gross electricity generation in the EU-27 in 1000 TWh/year divided by energy carrier[2]

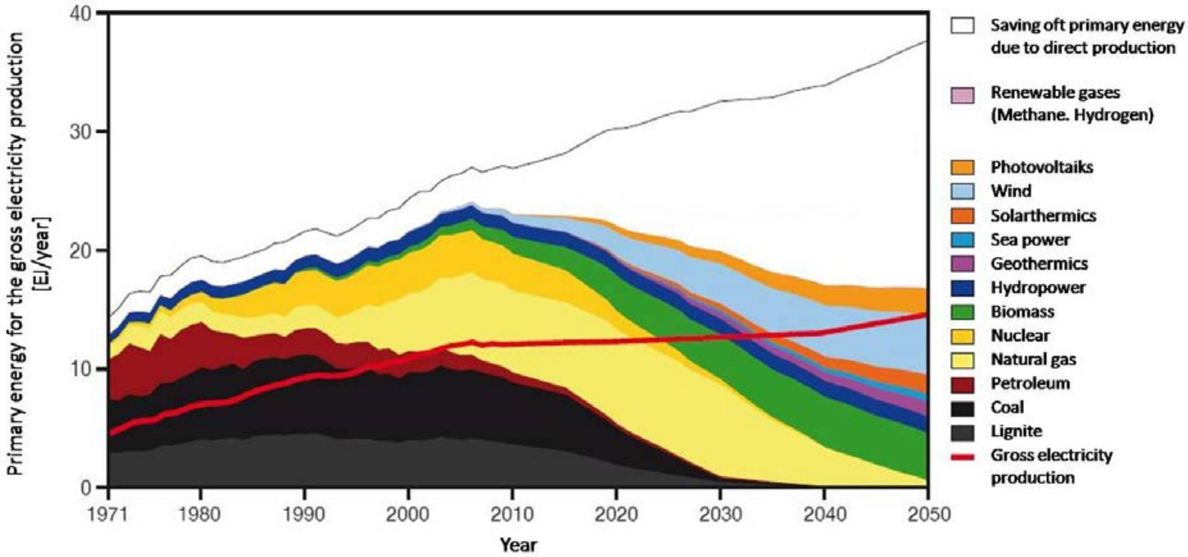

Fig. 2: Estimated primary energy used for the gross electricity generation in the EU-27 in EJ/year divided by energy carrier2

[2] **Wissenschaftlicher Beirat der Bundesregierung Globale Umweltveränderungen (WBGU). 2011.** *Hauptgutachten Welt im Wandel Gesellschaftsvertrag für eine Große Transformation.* Berlin : s.n., 2011. ISBN 978-3-936191-36-3.

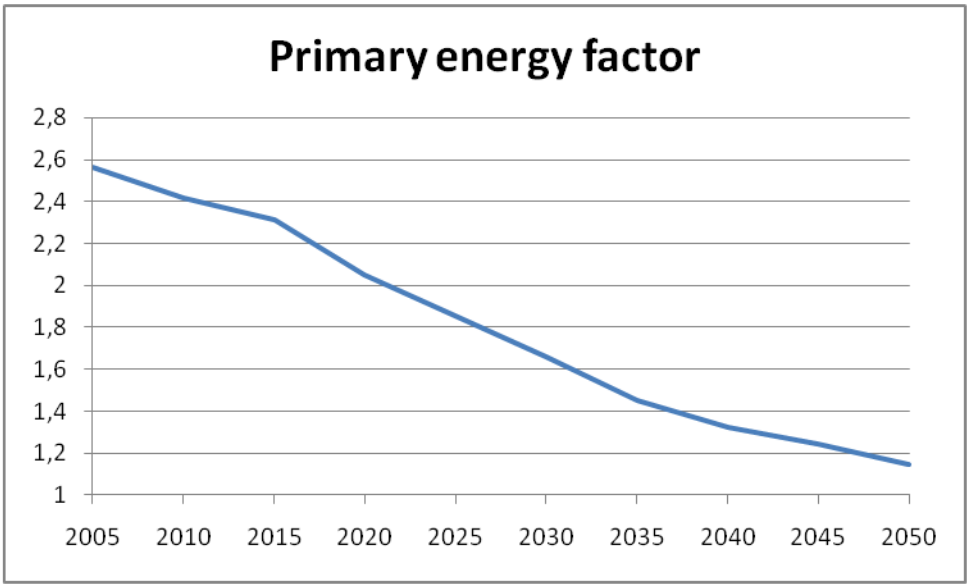

Fig. 3: Primary energy faktor from the year 2005 to 2050

The CO_2 -emission factor for electricity is calculated from the estimated use of primary energy in Fig. 2 taking the single CO_2 -emission factors of all the different contained energy carriers into account. The estimated CO_2 -emission factor for producing electricity in the EU-27 can be seen in Fig. 4.

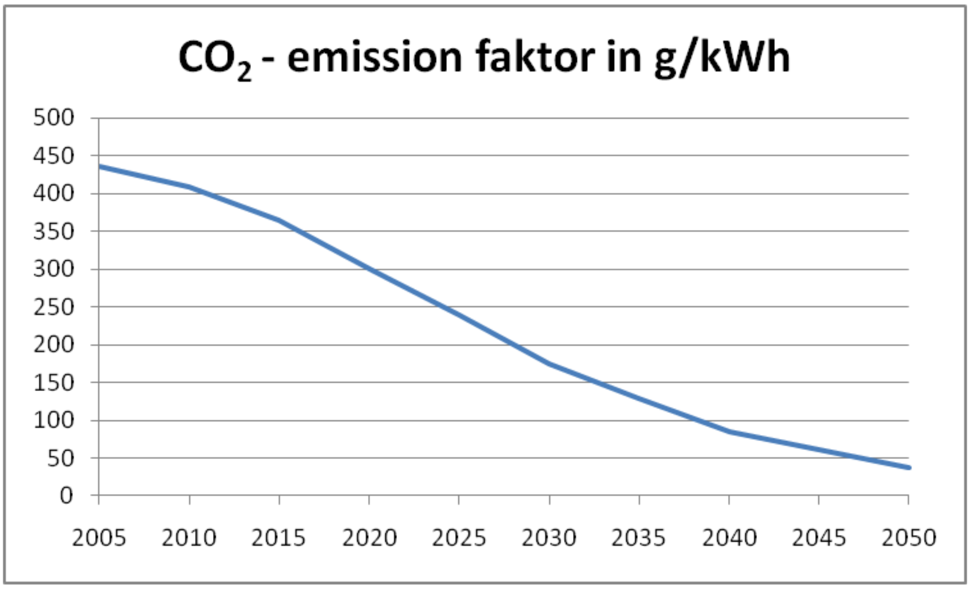

Fig. 4: CO_2 - emission faktor from the year 2005 to 2050 in g/kWh

3. Energy consumption of the European industry

3.1 Energy consumption divided by industry sectors

The energy consumption of the European industry reached a value of 3,133,762 GWh in the year 2009. The industry can be split up into 12 different sectors. They are:

- Iron & steel industry
- Non-ferrous metal industry
- Chemical industry
- Glass, pottery & building material industry
- Ore-extraction industry
- Food, drink & tobacco industry
- Textile, leather & clothing industry
- Paper and printing
- Transport equipment
- Machinery
- Wood and wood products
- Construction

The share and the amount of every industry sector can be seen in Fig. 5.

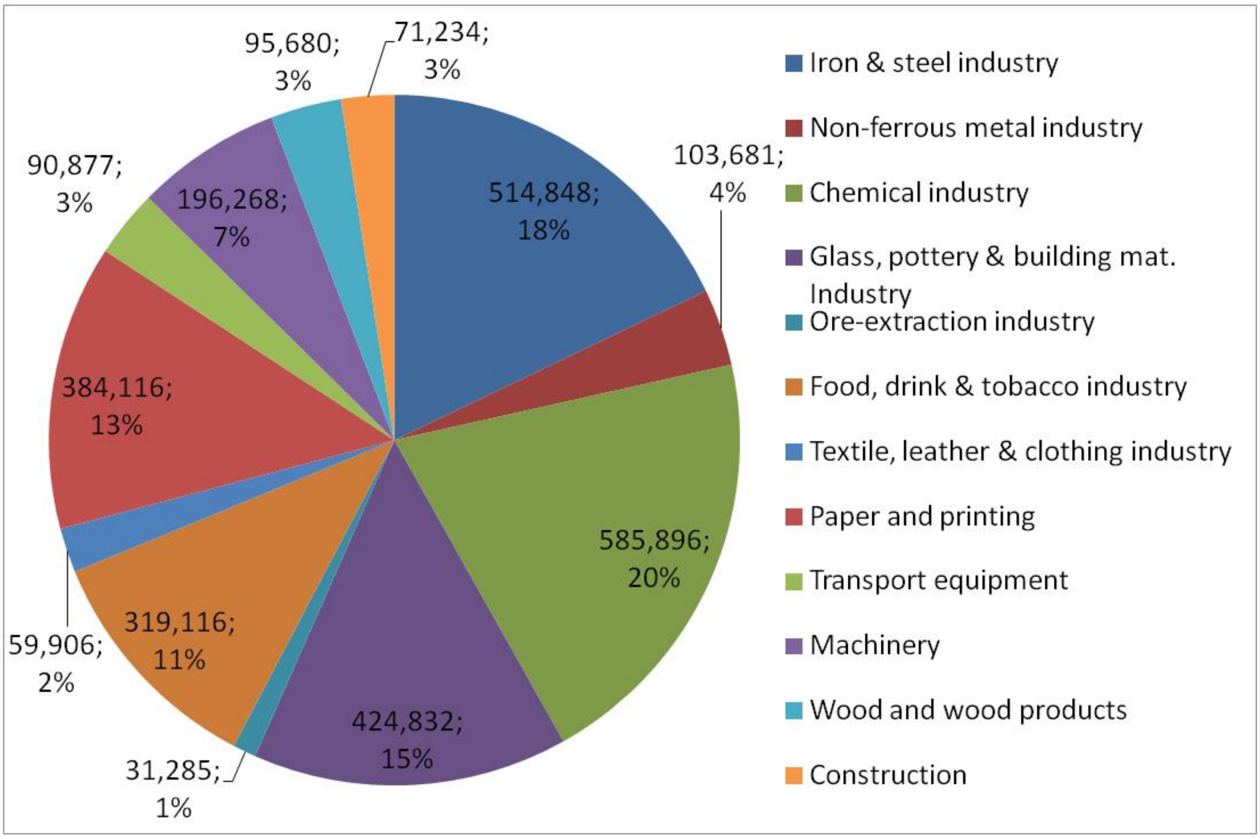

Fig. 5: Final energy consumption of the EU-27 industry in 2009 divided by industry sectors (Sum: 3,133,762 GWh)[3]

[3] **Eurostat - European Commission. 2011.** *Energy Balance Sheets — 2008-2009.* Luxembourg : Publications Office of the European Union, 2011.

3.1.1 Iron & steel industry

The energy consumption of the iron & steel industry in the EU-27 reaches a value of 514,848 GWh in the year 2009 as already shown in Fig. 5. So the iron & steel industry is the sector with the second highest energy consumption in Europe after the chemical industry. The distribution on a percentage basis to the different energy carriers can be seen in Fig. 6. It is noticeable that coke is the most important energy carrier with a share of 30 %. This can be explained with the need of coke for the blast furnace to produce raw iron. Other important energy carriers are gas (30 %), electrical power (21 %) and hard coal (13 %).

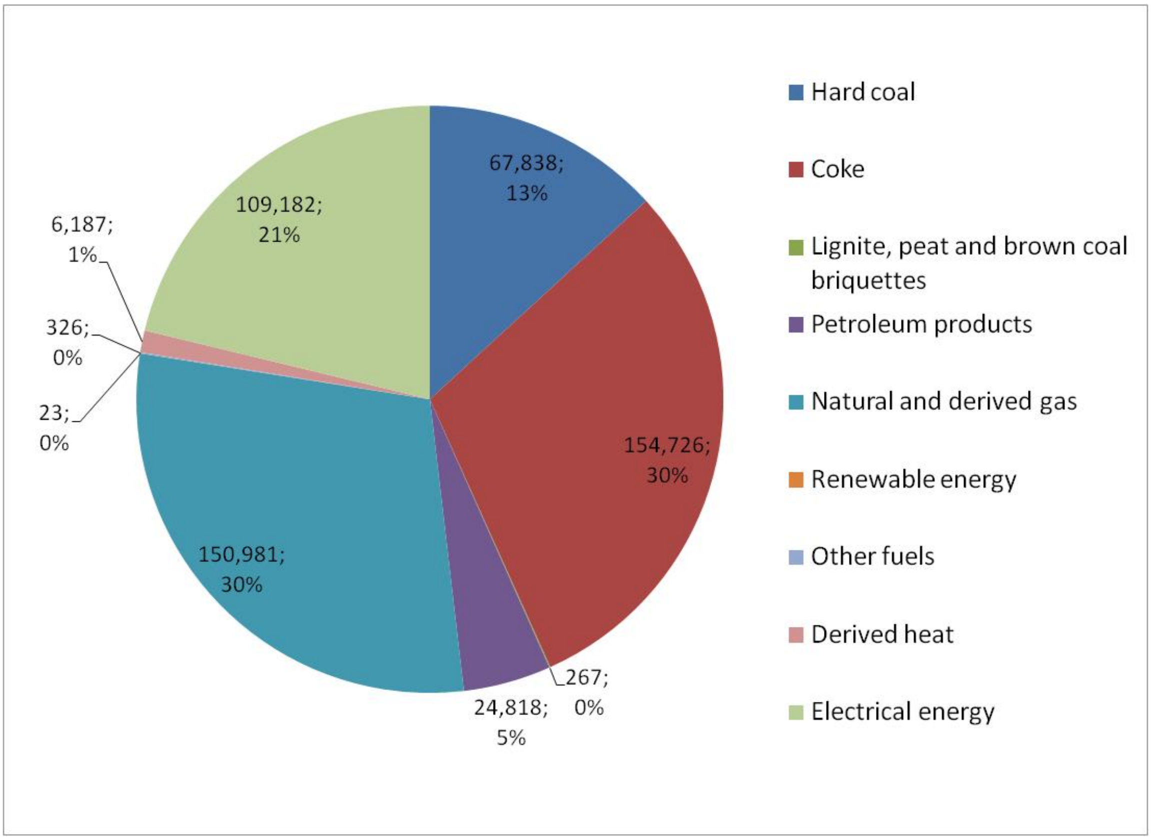

Fig. 6: Final energy consumption in the Iron & steel industry of the EU-27 in 2009 (Sum: 514,848 GWh)[3]

3.1.2 Non-ferrous metal industry

The energy consumption of the non-ferrous metal industry in the EU-27 reaches a value of 103,681 GWh in the year 2009 as already shown in Fig. 5. The distribution on a percentage basis to the different energy carriers can be seen in Fig. 7. It is interesting that electrical energy is the most important energy carrier for this energy sector by far. This can be explained be the high amount of electrical processes that already exist in this sector. Typical processes in this field are melting with the induction channel furnace and electrolyzing. The second considerable energy carrier is gas with an amount of 26 %.

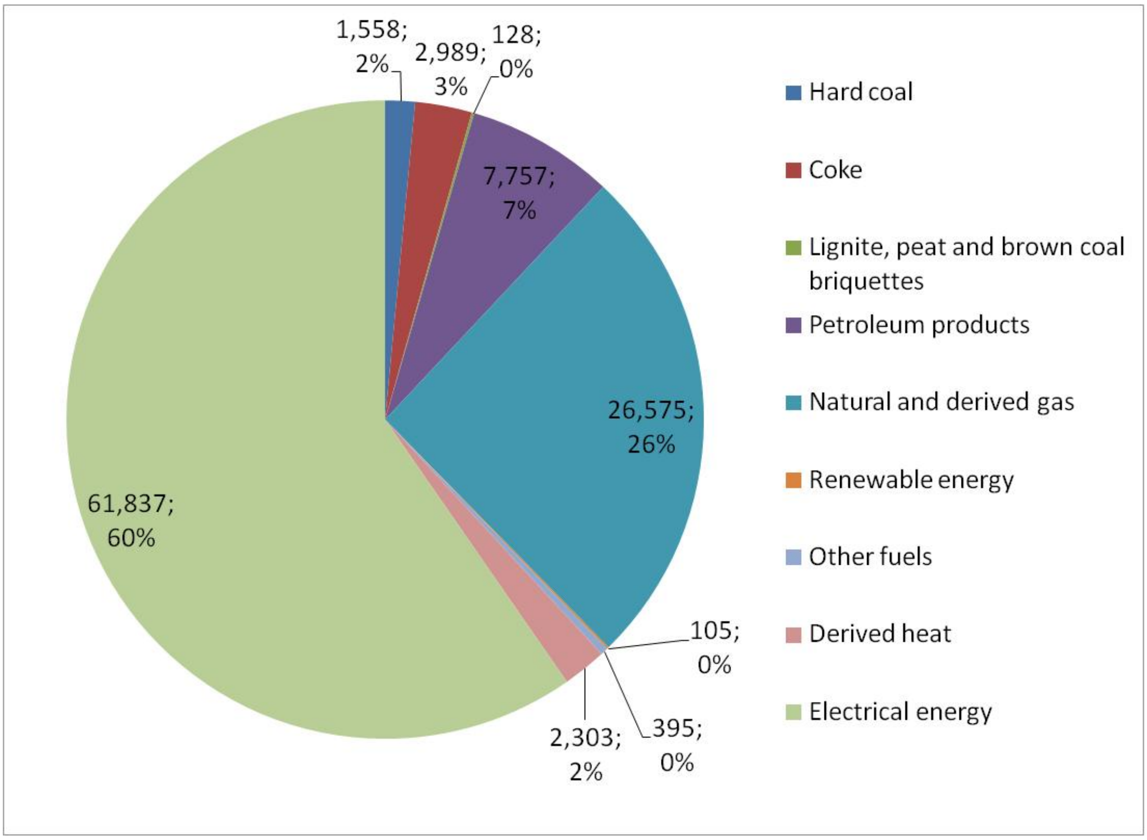

Fig. 7: Final energy consumption in the non-ferrous metal industry of the EU-27 in 2009 (Sum: 103,681 GWh) [3]

3.1.3 Chemical industry

The energy consumption of the chemical industry in the EU-27 reaches a value of 585,896 GWh in the year 2009 as already shown in Fig. 5. So the chemical industry is the sector with the highest energy consumption in Europe. The distribution on a percentage basis to the different energy carriers can be seen in Fig. 8. The most important energy carrier is gas with 33 %. It is followed by electrical energy with 30 %. Other important energy carriers are petroleum products (15 %) and derived heat (14 %).

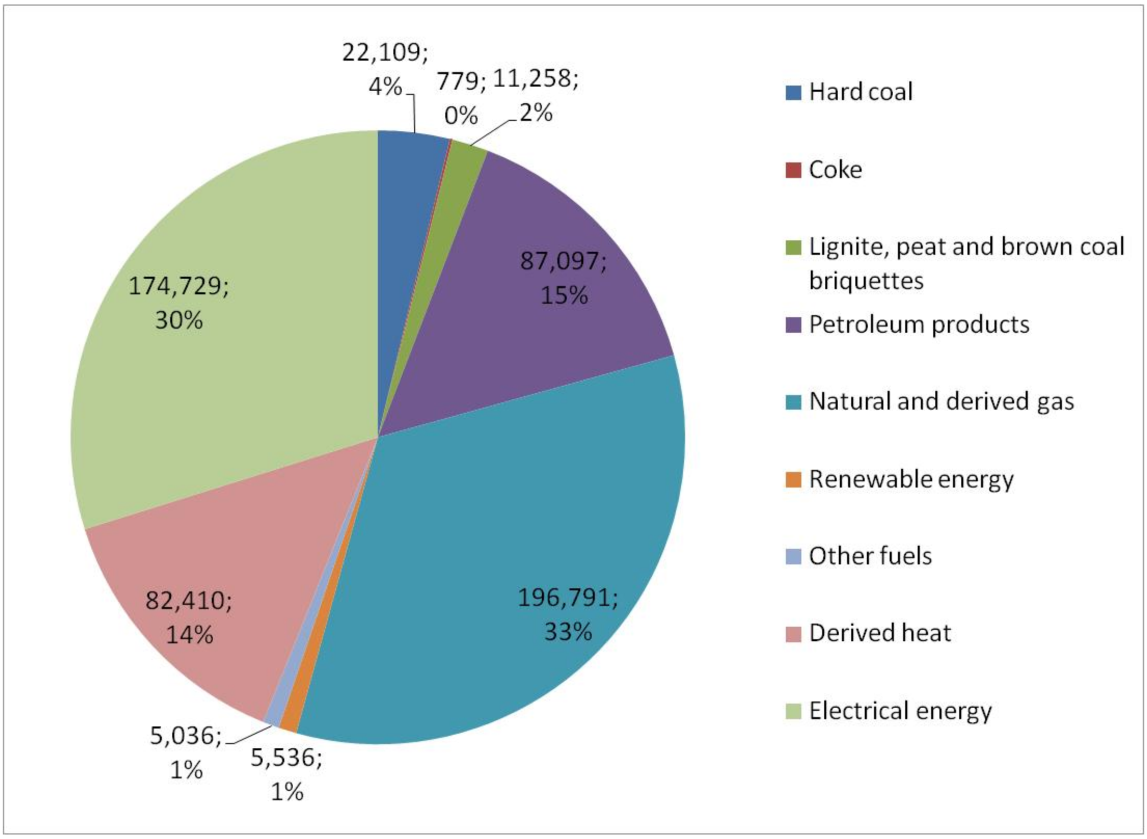

Fig. 8: Final energy consumption in the chemical industry of the EU-27 in 2009 (Sum: 585,896 GWh) [3]

3.1.4 Glass, pottery & building material Industry

The energy consumption of the glass, pottery and building material industry in the EU-27 reaches a value of 424,832 GWh in the year 2009 as already shown in Fig. 5. This industry sector is the sector with the third highest energy consumption in Europe. The distribution on a percentage basis to the different energy carriers can be seen in Fig. 9. The most important energy carrier is gas with 36 %. It is followed by petroleum products with 26 %. Other important energy carriers are electrical energy (17 %) and also hard coal (9 %).

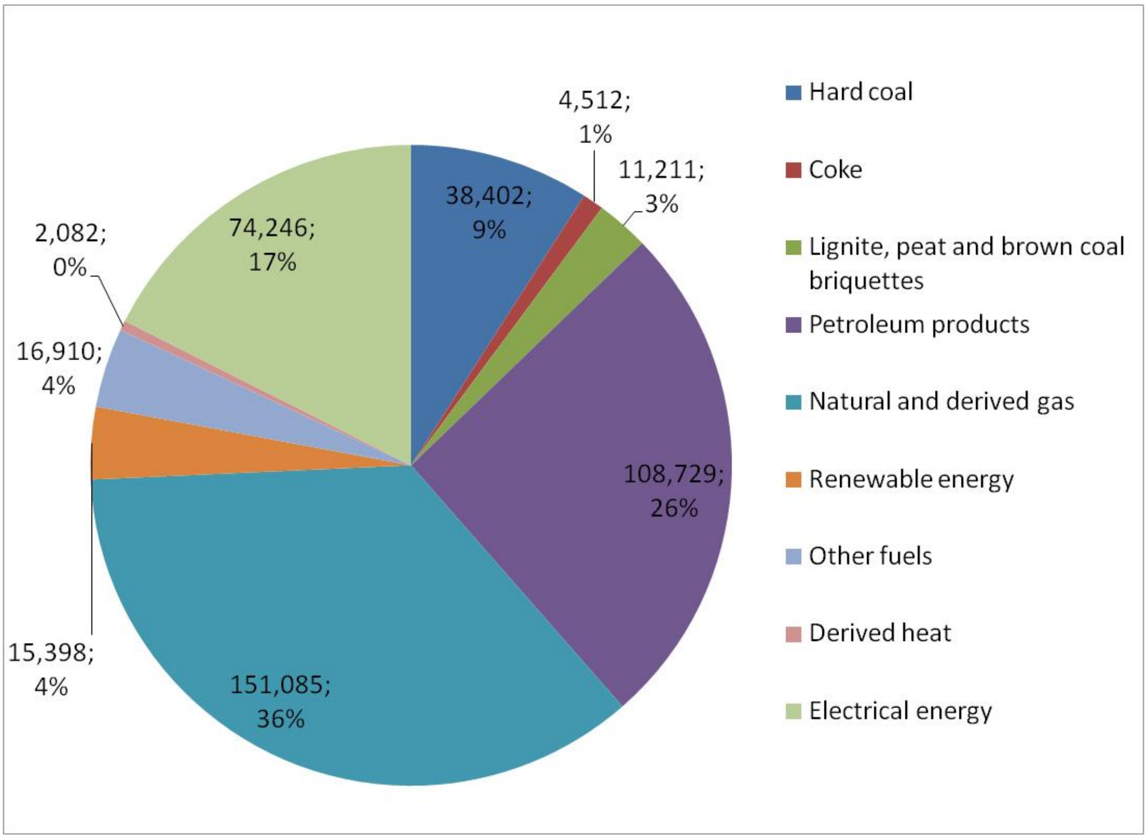

Fig. 9: Final energy consumption in the glass, pottery and building material industry of the EU-27 in 2009 (Sum: 424,832 GWh) [3]

3.1.5 Ore-extraction industry

The energy consumption of the ore-extraction industry in the EU-27 reaches a value of 31,285 GWh in the year 2009 as already shown in Fig. 5. This industry sector has a relatively low level of energy consuming in Europe. The distribution on a percentage basis to the different energy carriers can be seen in Fig. 10. The most important energy carrier is electrical energy with 45 %. It is followed by petroleum products with 26 % and gas with 17 %.

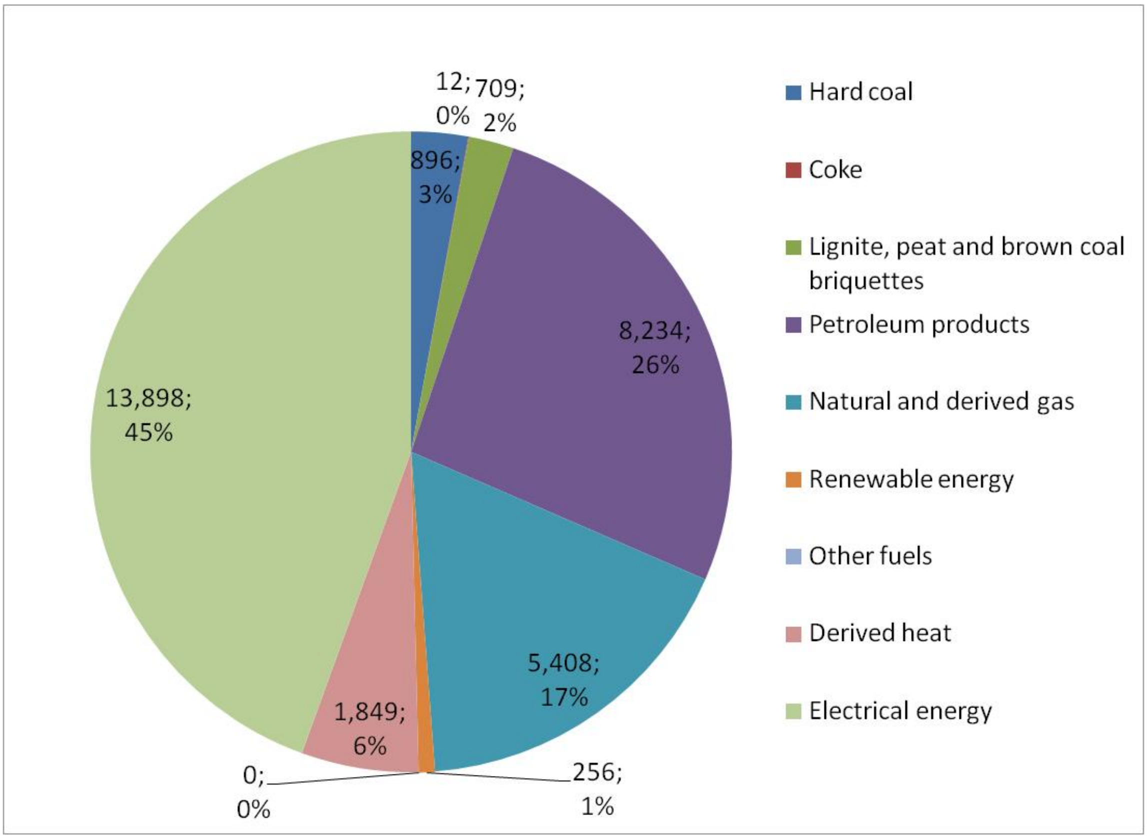

Fig. 10: Final energy consumption in the ore-extraction industry of the EU-27 in 2009 (Sum: 31,285 GWh) [3]

3.1.6 Food, drink & tobacco industry

The energy consumption of the food, drink and tobacco industry in the EU-27 reaches a value of 319,116 GWh in the year 2009 as already shown in Fig. 5. This industry sector has a relatively high level of energy consuming in Europe. The distribution on a percentage basis to the different energy carriers can be seen in Fig. 11. The most important energy carrier is gas with 41 %. It is followed by electrical energy with 34 % and petroleum products with 11 %.

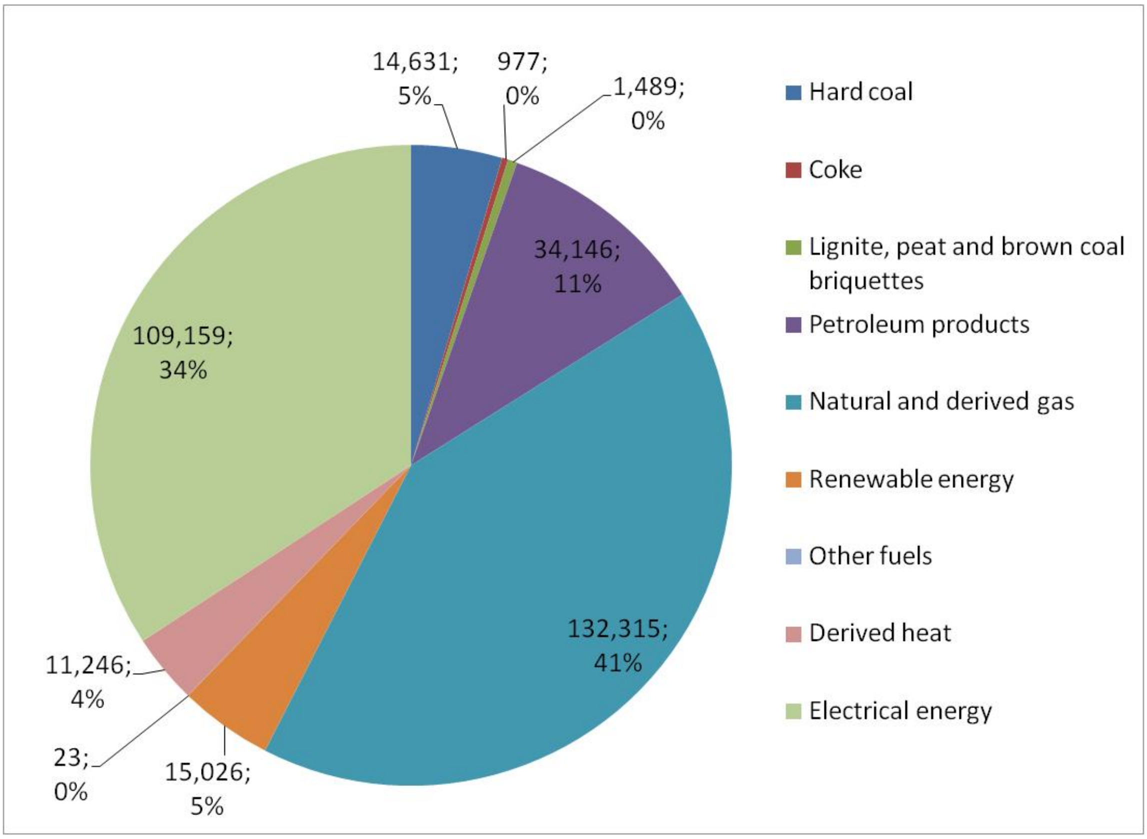

Fig. 11: Final energy consumption in the food, drink and tobacco industry of the EU-27 in 2009 (Sum: 319,116 GWh) [3]

3.1.7 Textile, leather & clothing industry

The energy consumption of the textile, leather and clothing industry in the EU-27 reaches a value of 55,906 GWh in the year 2009 as already shown in Fig. 5. This industry sector has a relatively low level of energy consuming in Europe. The distribution on a percentage basis to the different energy carriers can be seen in Fig. 12. The most important energy carrier is gas with 44 %. It is followed by electrical energy with 39 % and petroleum products with 11 %.

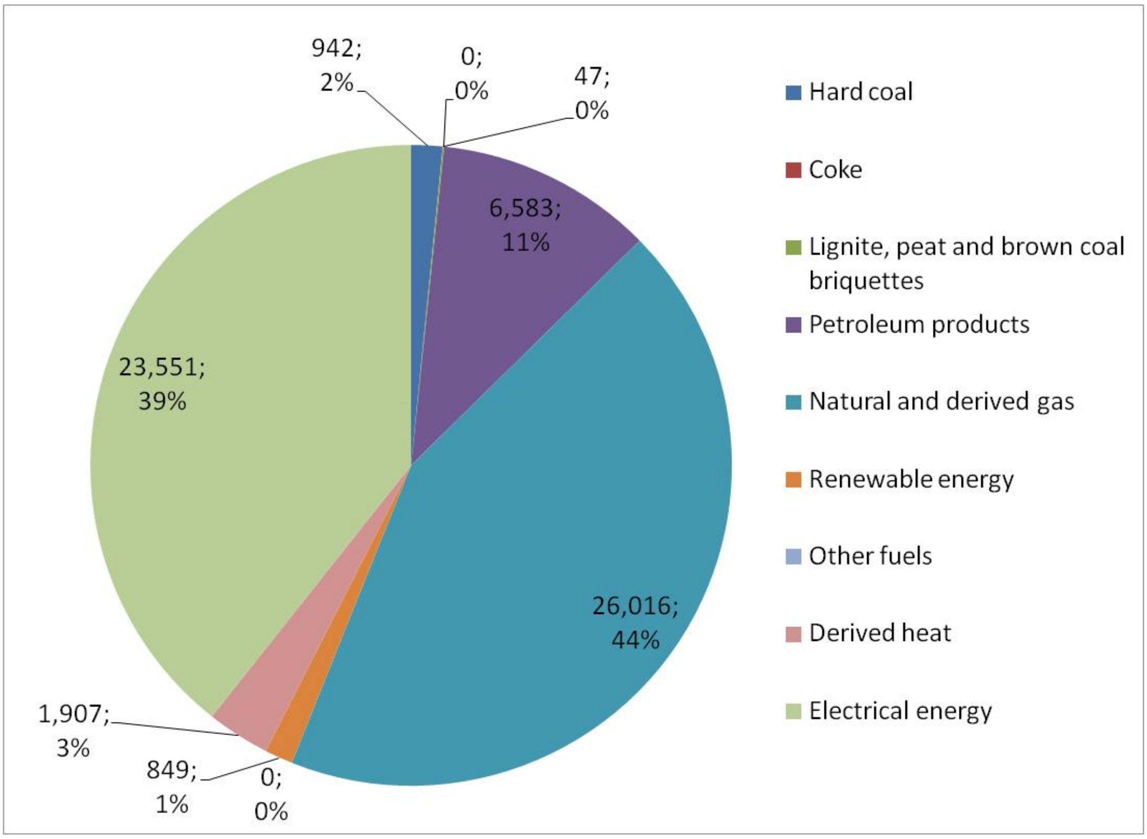

Fig. 12: Final energy consumption in the textile, leather and clothing industry of the EU-27 in 2009 (Sum: 59,906 GWh) [3]

3.1.8 Paper and printing

The energy consumption of the paper and printing industry in the EU-27 reaches a value of 384,116 GWh in the year 2009 as already shown in Fig. 5. This industry sector is the sector with the fourth highest energy consumption in Europe. The distribution on a percentage basis to the different energy carriers can be seen in Fig. 13. The most important energy carriers are renewable energies with 32 %. It is followed by electrical energy with 32 % and gas 22 %.

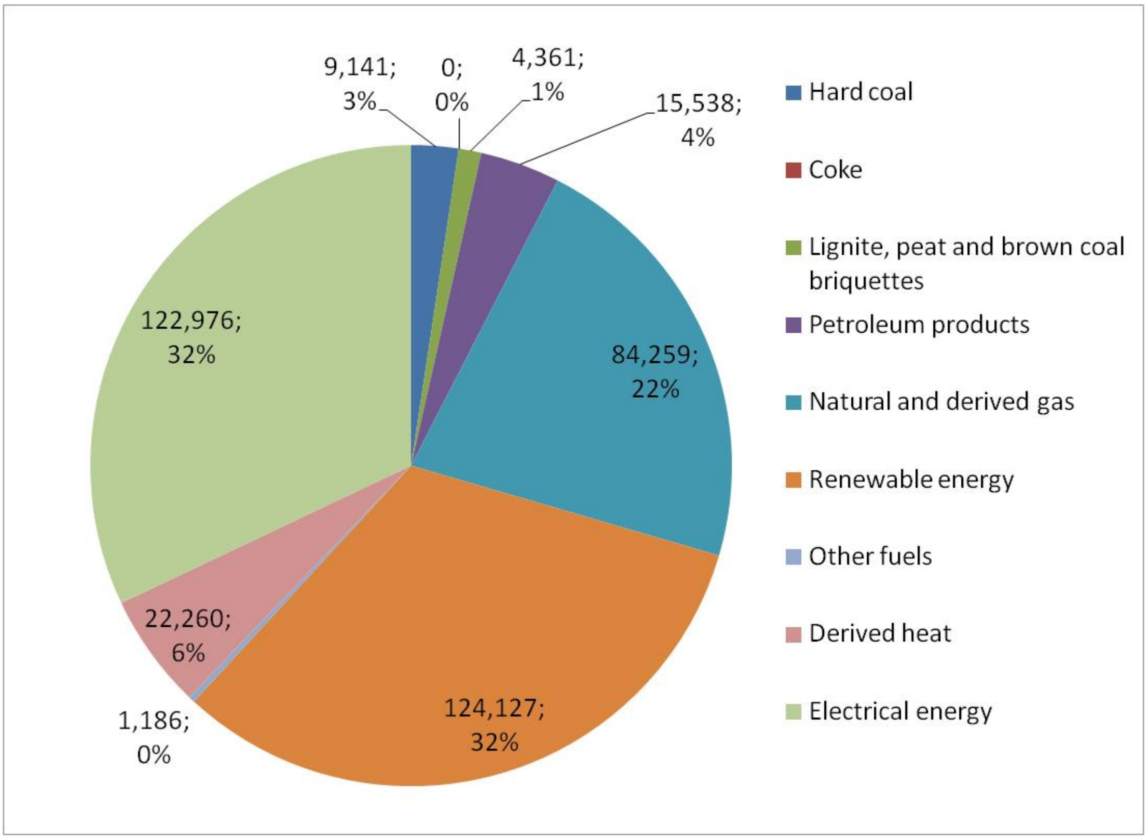

Fig. 13: Final energy consumption in the paper and printing industry of the EU-27 in 2009 (Sum: 384,116 GWh) [3]

3.1.9 Transport equipment

The energy consumption of the transport equipment industry in the EU-27 reaches a value of 90,877 GWh in the year 2009 as already shown in Fig. 5. This industry sector has a relatively low level of energy consuming in Europe. The distribution on a percentage basis to the different energy carriers can be seen in Fig. 14. The most important energy carrier is electrical energy with 53 %. It is followed by gas with 32 % and derived heat with 8 %.

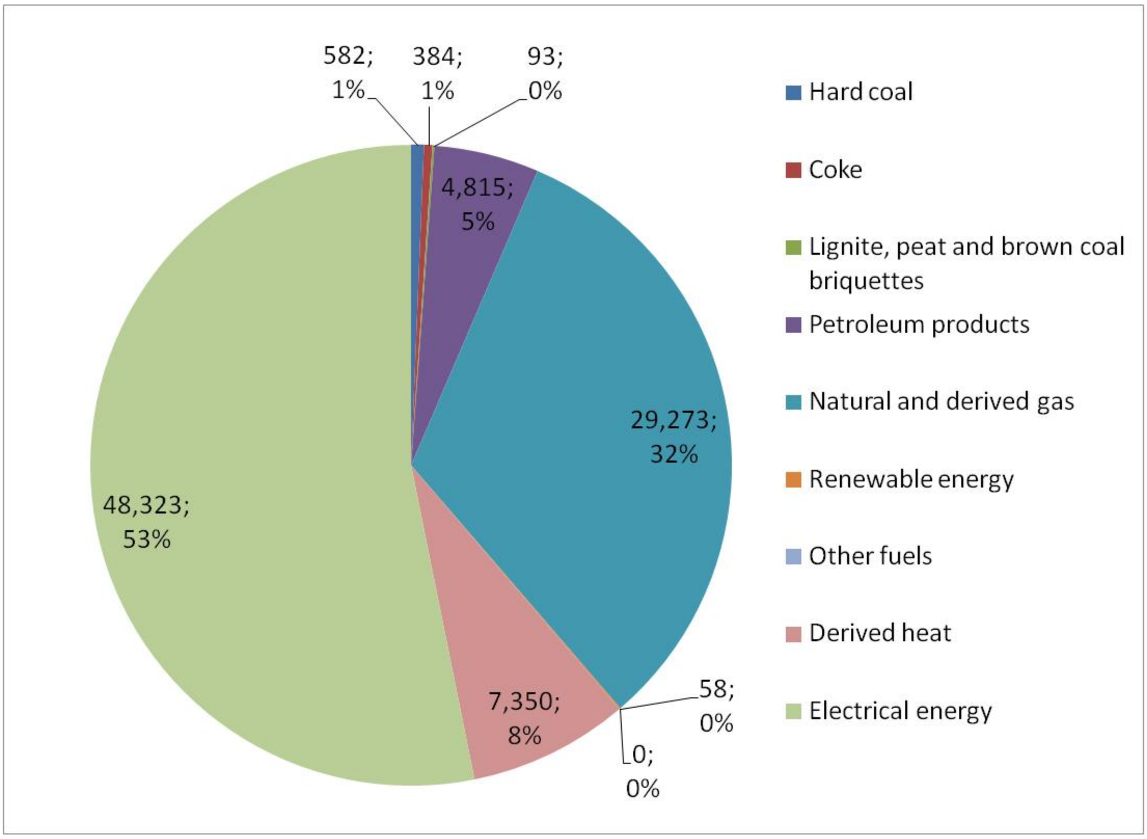

Fig. 14: Final energy consumption in the transport equipment industry of the EU-27 in 2009 (Sum: 90,877 GWh) [3]

3.1.10 Machinery

The energy consumption of the machinery industry in the EU-27 reaches a value of 196,268 GWh in the year 2009 as already shown in Fig. 5. The distribution on a percentage basis to the different energy carriers can be seen in Fig. 15. The most important energy carrier is electrical energy with 48 %. It is followed by gas with 39 % and petroleum products with 10 %.

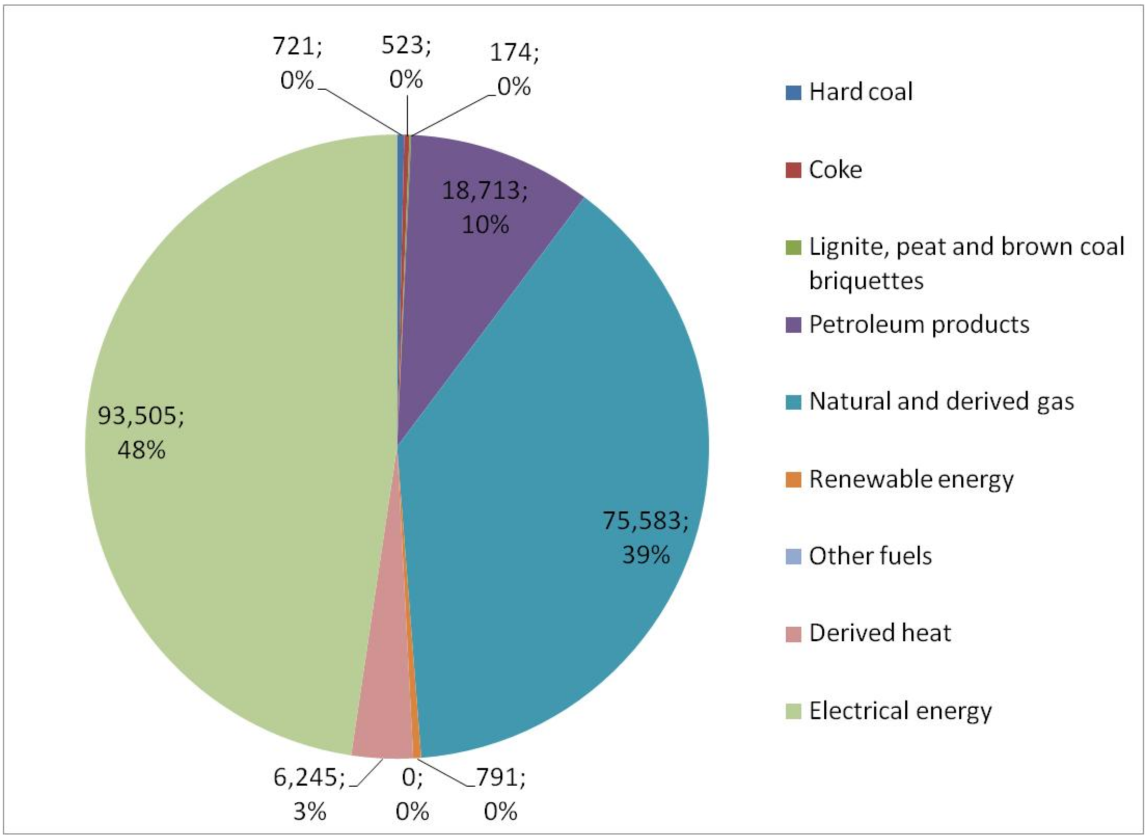

Fig. 15: Final energy consumption in the machinery industry of the EU-27 in 2009 (Sum: 196,268 GWh) 3

3.1.11 Wood and wood products

The energy consumption of the wood and wood products industry in the EU-27 reaches a value of 95,680 GWh in the year 2009 as already shown in Fig. 5. This industry sector has a relatively low level of energy consuming in Europe. The distribution on a percentage basis to the different energy carriers can be seen in Fig. 16. The most important energy carriers are renewable energies with 56 %. It is followed by electrical energy with 26 %

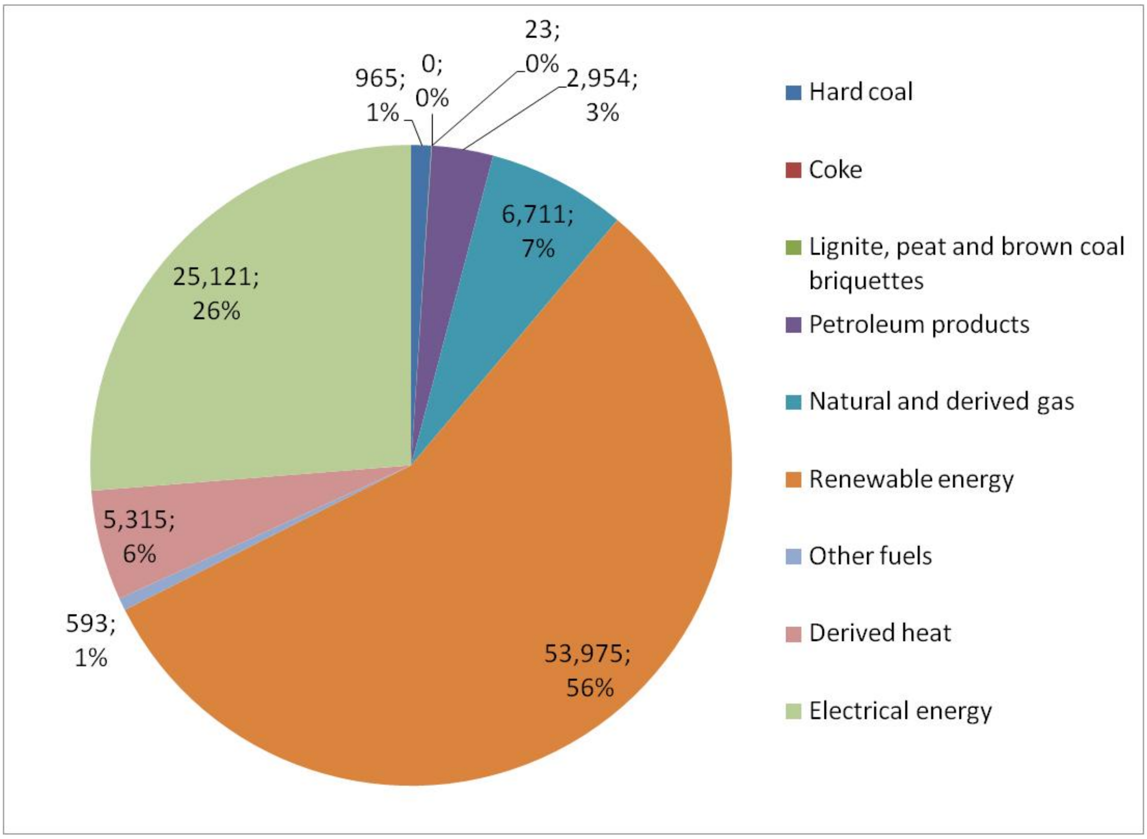

Fig. 16: Final energy consumption in the wood and wood product industry of the EU-27 in 2009 (Sum: 95,680 GWh) [3]

3.1.12 Construction

The energy consumption of the construction industry in the EU-27 reaches a value of 71,234 GWh in the year 2009 as already shown in Fig. 5. This industry sector has a relatively low level of energy consuming in Europe. The distribution on a percentage basis to the different energy carriers can be seen in Fig. 17. The most important energy carriers are petroleum products with 55 %. It is followed by electrical energy with 25 % and gas with 17 %.

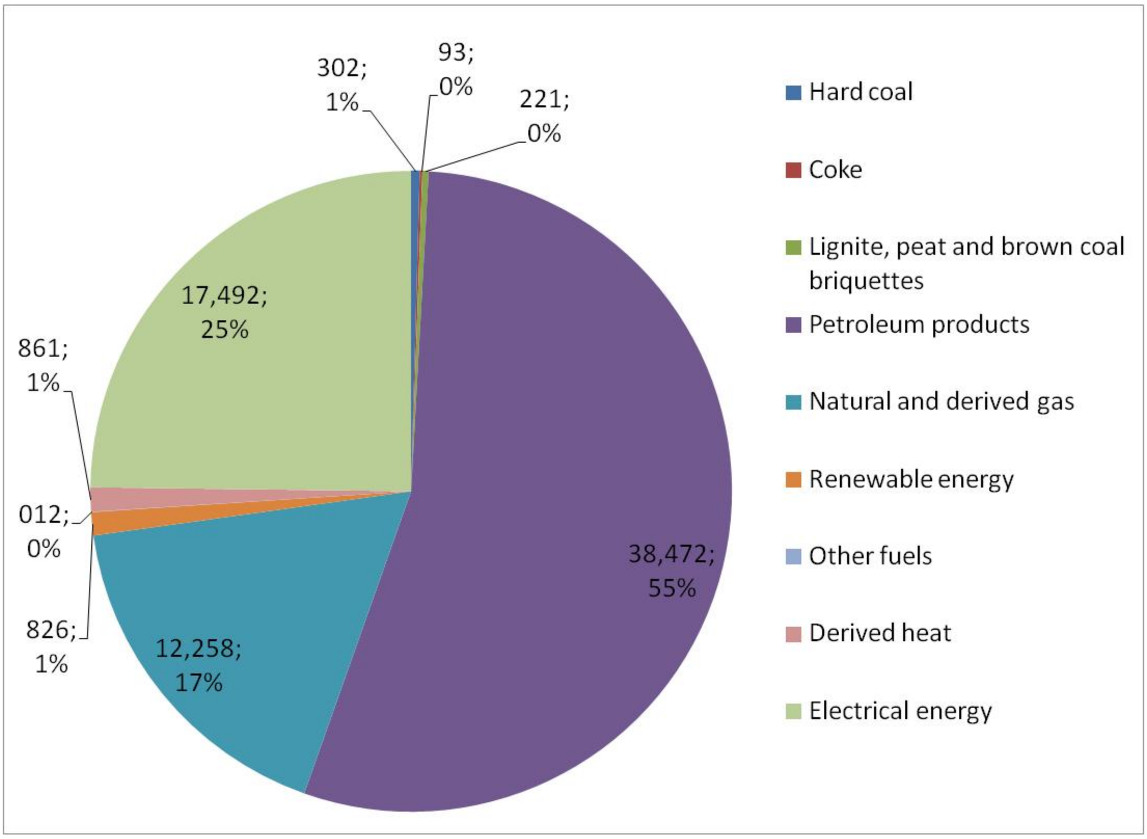

Fig. 17: Final energy consumption in the construction industry of the EU-27 in 2009 (Sum: 71,234 GWh) 3

3.2 Energy consumption divided by energy source

In Fig. 18 the final energy of the industry in the EU-27 is presented divided by energy supplies. The sum of the final energy is the same like in Fig. 5 and has a value of 3,133,762 GWh. It can be seen that electrical power has already the biggest share on the final energy consumption with 31 %. The second important energy carrier is gas with 30 %. It is followed by petroleum products with 14 %, renewable energy with 7 %, derived heat with 6 % and coke and hard coal with each 5 %. The other two energy carriers lignite, peat and brown coal briquettes and other have each 1 %.

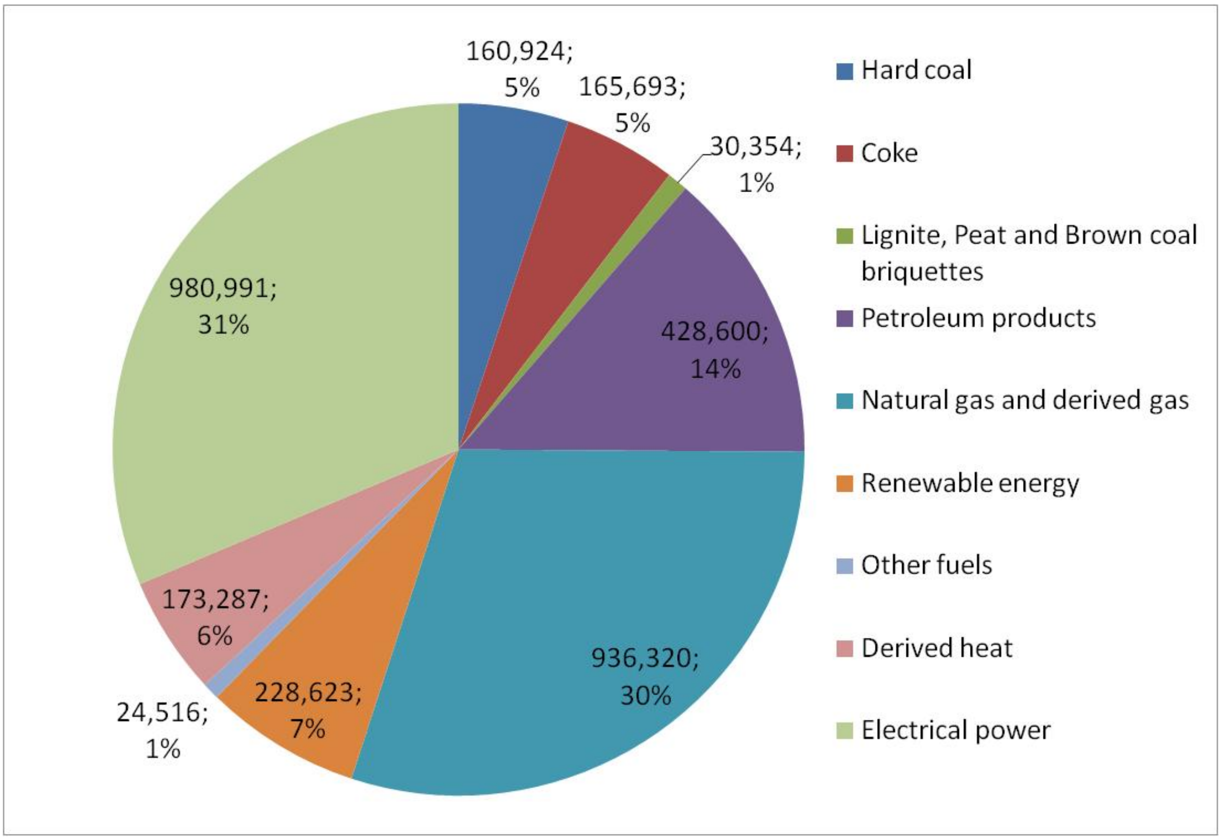

Fig. 18: Final energy consumption of the EU-27 industry in 2009 divided by energy carrier (Sum: 3,133,762 GWh) [3]

3.2.1 Hard coal

The energy consumption of hard coal in the EU-27 reaches a value of 160,924 GWh in the year 2009 as already shown in Fig. 18. This industry sector has a relatively low level of energy consuming in Europe. The distribution on a percentage basis to the different industry sectors can be seen in Fig. 19. The iron and steel industry is the most important industry sector with a share of 43 %. It is followed by the glass, pottery and building material sector with 24 %, the chemical industry with 14 % and the food, drink and tobacco industry with 9 %.

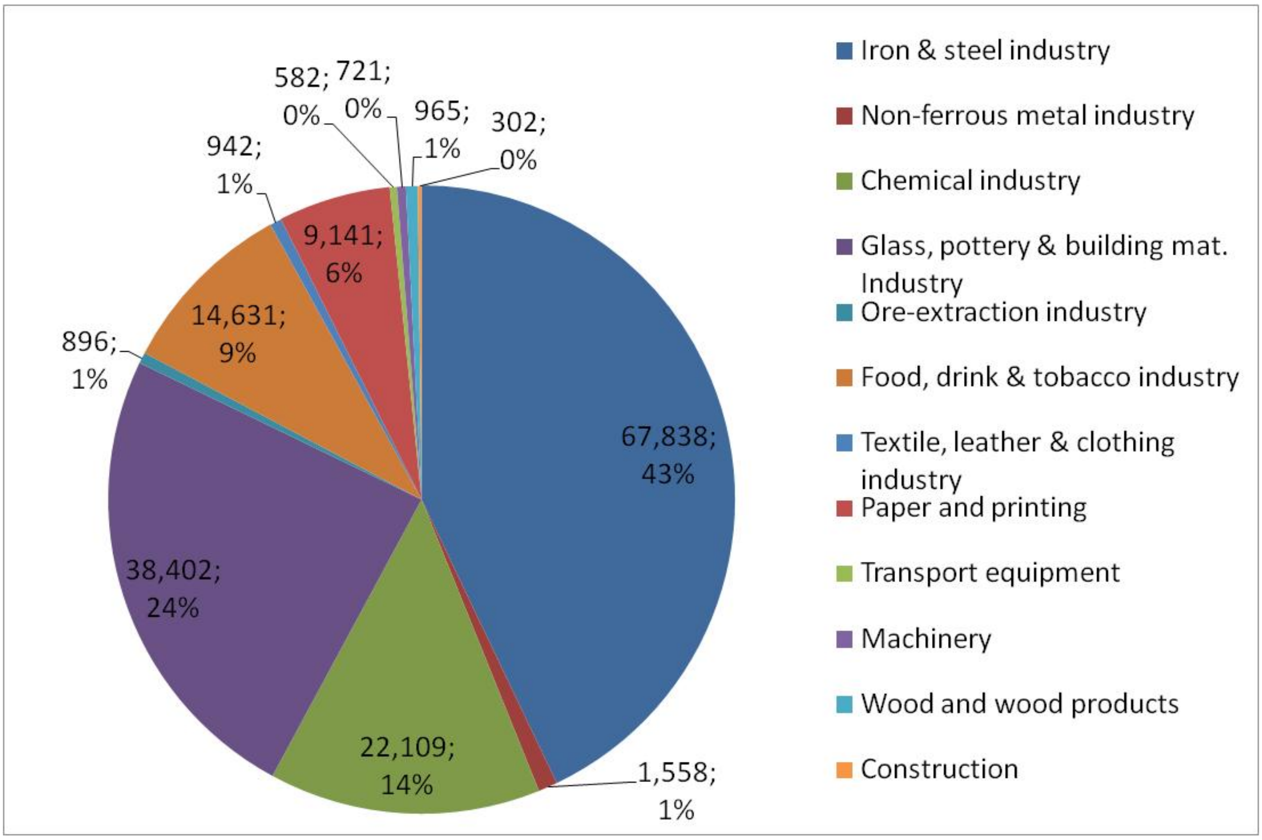

Fig. 19: Final energy consumption in the industry of the EU-27 covered by hard coal in 2009 (Sum: 160,924 GWh) [3]

3.2.2 Coke

The energy consumption of coke in the EU-27 reaches a value of 165,693 GWh in the year 2009 as already shown in Fig. 18. This industry sector has a relatively low level of energy consuming in Europe. The distribution on a percentage basis to the different industry sectors can be seen in Fig. 20. It is remarkable that 94 % of the energy is used by the iron and steel industry. Coke is needed for the blast furnace to produce raw iron. Other industry sectors do not have high coke consumptions.

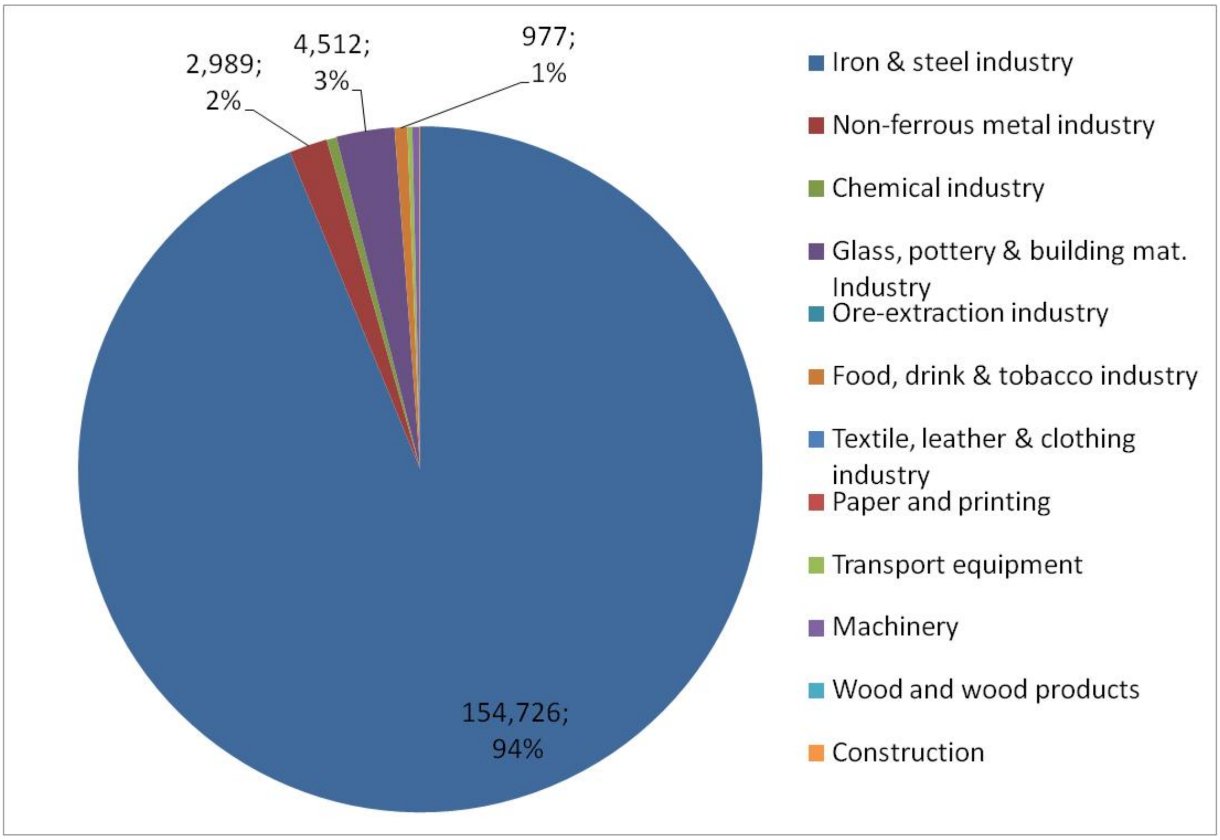

Fig. 20: Final energy consumption in the industry of the EU-27 covered by coke in 2009 (Sum: 165,693 GWh) [3]

3.2.3 Lignite, Peat and Brown coal briquettes

The energy consumption of lignite, Peat and Brown coal briquettes in the EU-27 reaches a value of 30,354 GWh in the year 2009 as already shown in Fig. 18. This industry sector has a relatively low level of energy consuming in Europe. The distribution on a percentage basis to the different industry sectors can be seen in Fig. 21. The chemical industry is the most important industry sector with a share of 38 %. It is followed by the glass, pottery and building material sector with 37 % and the paper and printing industry with 15 %.

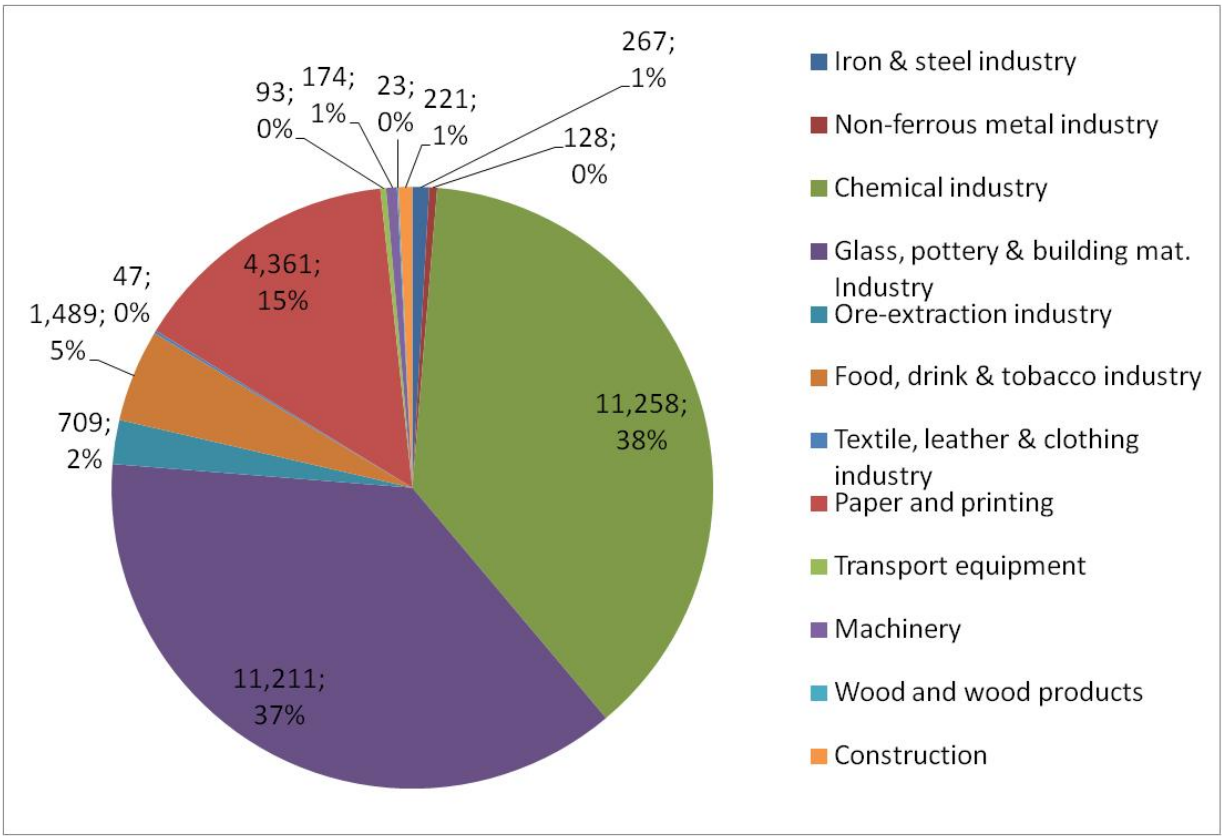

Fig. 21: Final energy consumption in the industry of the EU-27 covered by lignite, peat and brown coal briquettes in 2009 (Sum: 30,354 GWh) [3]

3.2.4 Petroleum products

The energy consumption of petroleum products in the EU-27 reaches a value of 428,600 GWh in the year 2009 as already shown in Fig. 18. This energy carrier is the sector with the third highest energy consumption in Europe. The distribution on a percentage basis to the different industry sectors can be seen in Fig. 22. The glass, pottery and building material industry is the most important industry sector with a share of 31 %. It is followed by the chemical industry sector with 24 %, the construction industry with 11 % and the food drink and tobacco industry with 10 %

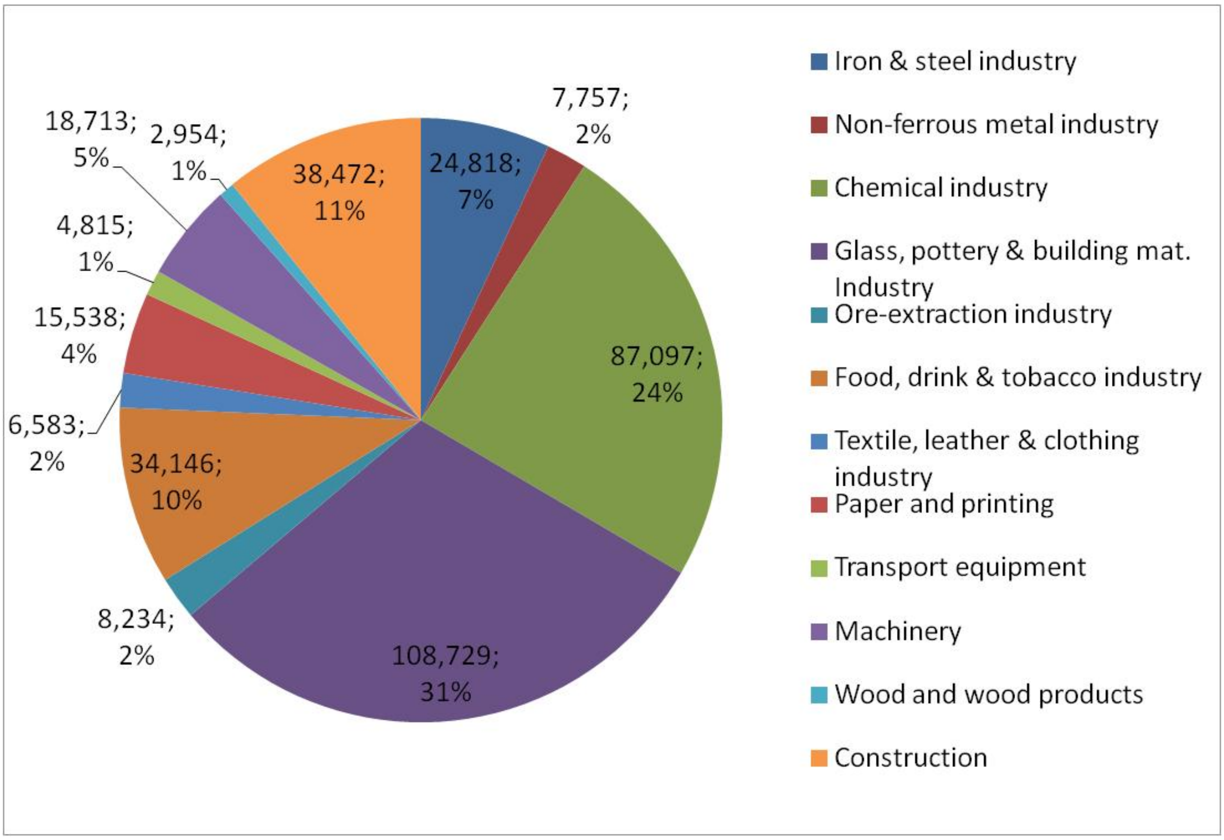

Fig. 22: Final energy consumption in the industry of the EU-27 covered by crude oil and petroleum products in 2009 (Sum: 428,600 GWh) [3]

3.2.5 Natural gas and derived gas

The energy consumption of natural and derived gas in the EU-27 reaches a value of 936,320 GWh in the year 2009 as already shown in Fig. 18. This energy carrier is the sector with the second highest energy consumption in Europe. The distribution on a percentage basis to the different industry sectors can be seen in Fig. 23. Close to every industry sector uses gas as an energy carrier for their production. The biggest share has the chemical industry with 22 %. It is followed by the iron and steel industry and the glass, pottery and building material industry with each 17 %. Other important industry sectors using gas are the food, drink and tobacco industry with 15 %, the paper and printing industry with 9 % and the machinery industry with 8 %.

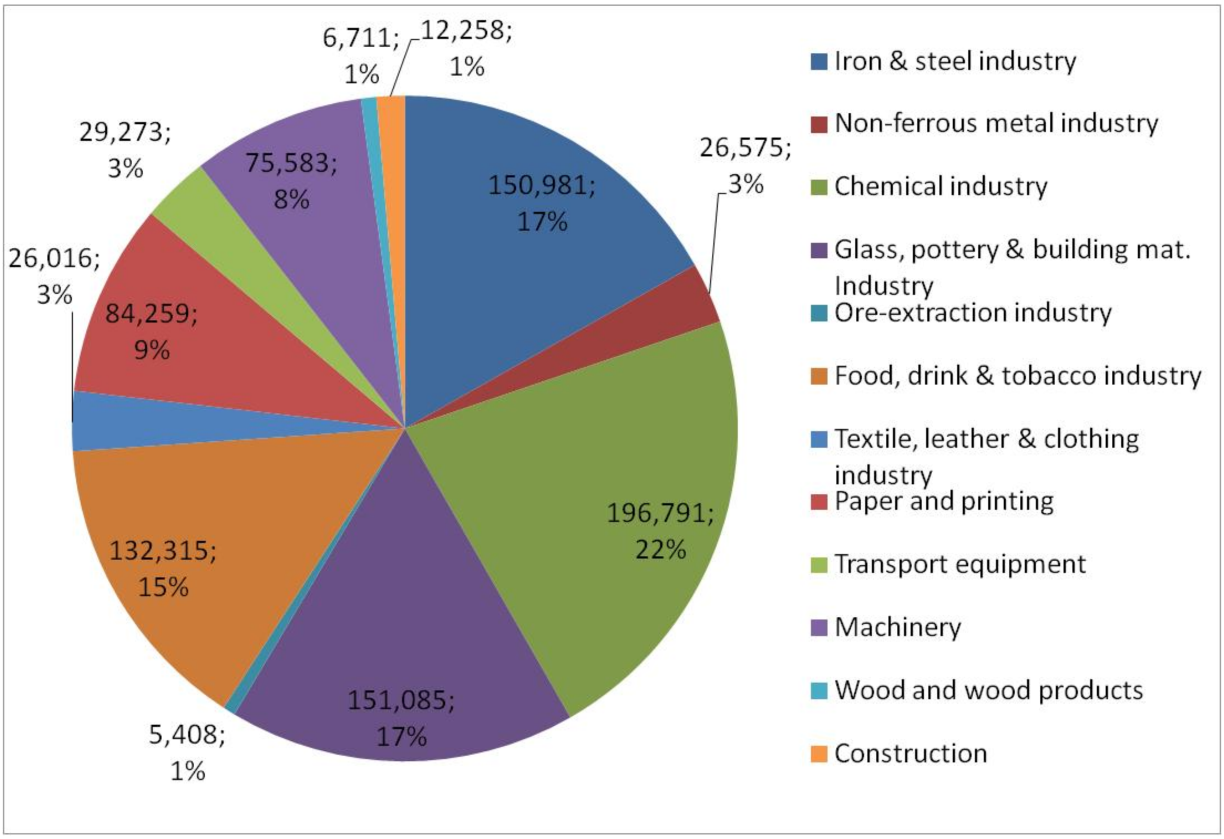

Fig. 23: Final energy consumption in the industry of the EU-27 covered by natural and derived gas in 2009 (Sum: 936,320 GWh) [3]

3.2.6 Renewable energy

The energy consumption of renewable energies in the EU-27 reaches a value of 228,623 GWh in the year 2009 as already shown in Fig. 18. Energy carrier gets more and more important. Renewable energies are already the fourth most important energy carrier in the European industry. The distribution on a percentage basis to the different industry sectors can be seen in Fig. 24. The biggest share by a long way has the paper and printing industry with 57 %. It is followed by the wood and wood products industry with 25 % and the glass, pottery and building material industry and food, drink and tobacco industry with each 7 %.

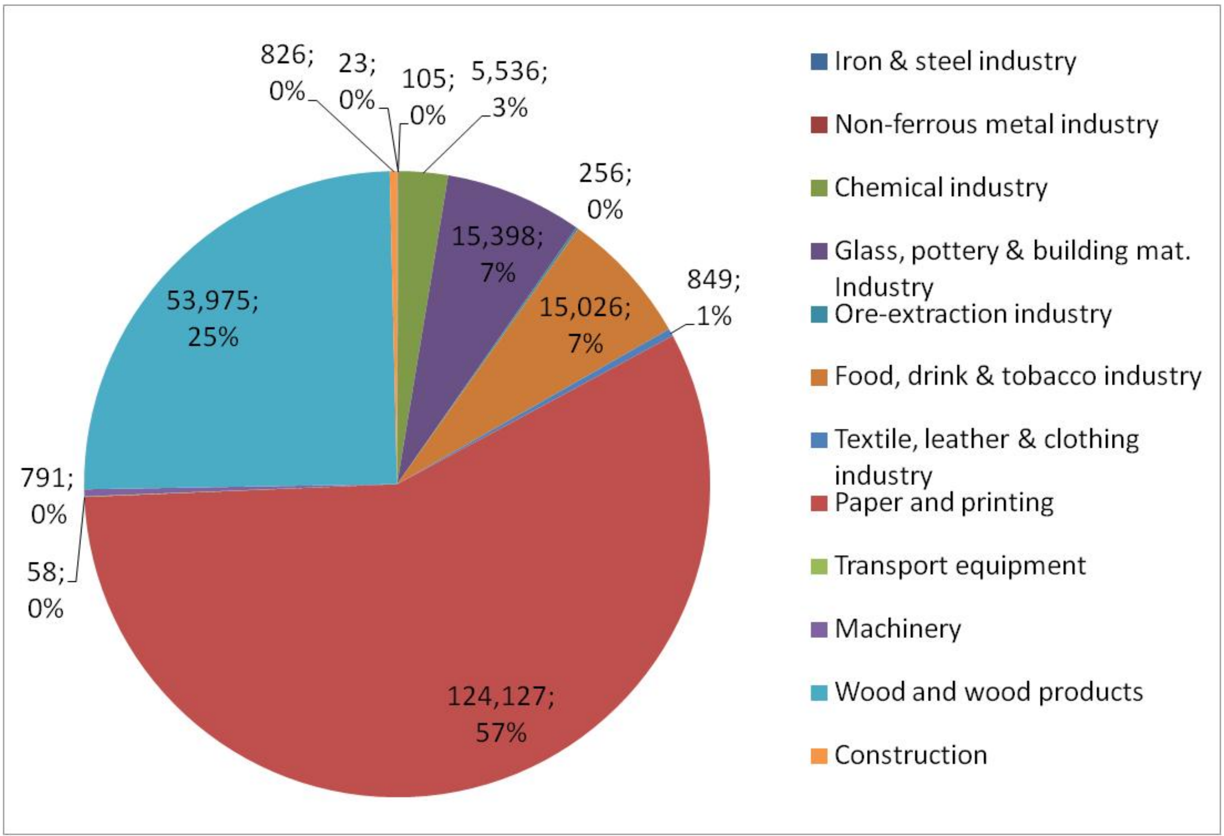

Fig. 24: Final energy consumption in the industry of the EU-27 covered by renewable energies in 2009 (Sum: 228,623 GWh) [3]

3.2.7 Other fuels

The energy consumption of other fuels in the EU-27 reaches a value of 24,516 GWh in the year 2009 as already shown in Fig. 18. This energy carrier has the lowest energy consumption in Europe. The distribution on a percentage basis to the different industry sectors can be seen in Fig. 25. The biggest share has the machinery industry with 69 %. It is followed by the chemical industry with 21 %.

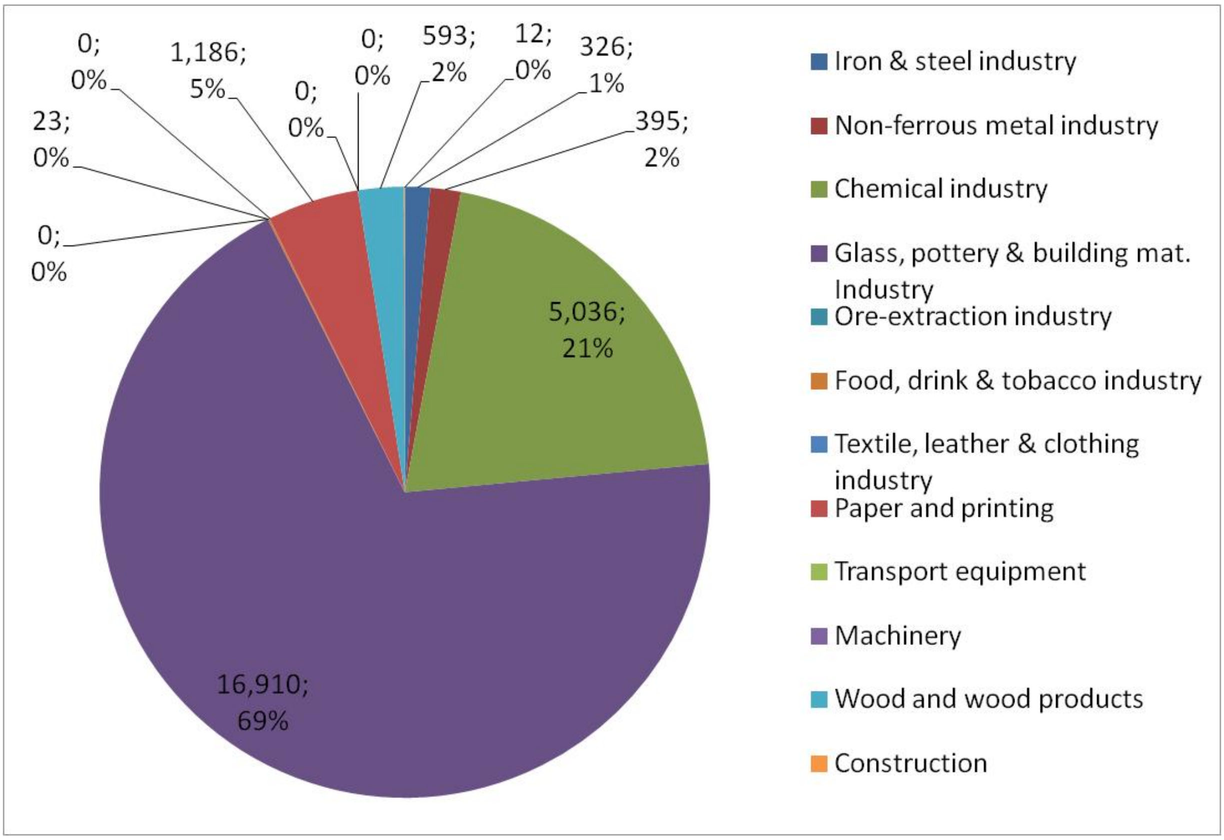

Fig. 25: Final energy consumption in the industry of the EU-27 covered by other fuels in 2009 (Sum: 24,516 GWh) [3]

3.2.8 Derived heat

The energy consumption of derived heat in the EU-27 reaches a value of 173,287 GWh in the year 2009 as already shown in Fig. 18. This industry sector has a relatively low level of energy consuming in Europe. The distribution on a percentage basis to the different industry sectors can be seen in Fig. 26. The biggest share has the chemical industry with 55 %. It is followed by the paper and printing industry with 15 %. Beside this two industry sectors close to every other sector uses derived heat as well.

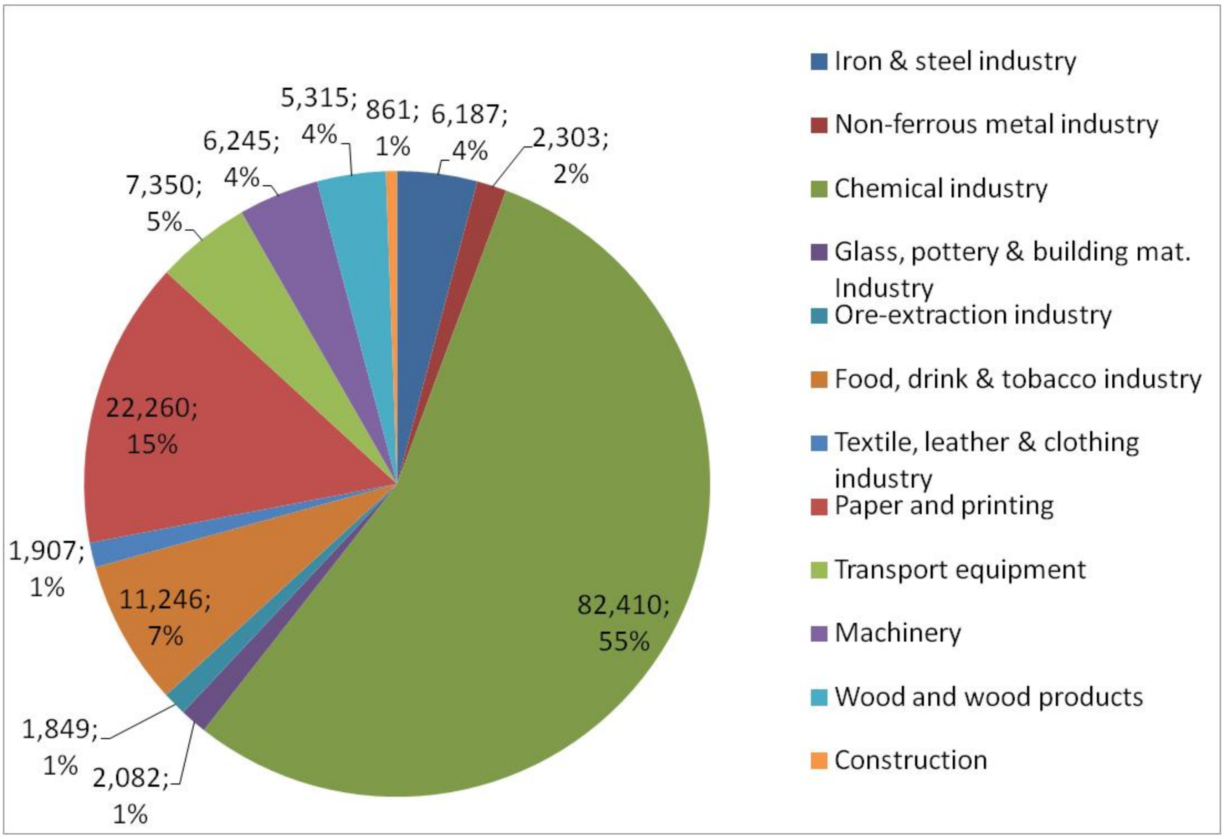

Fig. 26: Final energy consumption in the industry of the EU-27 covered by derived heat in 2009 (Sum: 173,287 GWh) [3]

3.2.9 Electrical power

The energy consumption of electrical energy in the EU-27 reaches a value of 980,994 GWh in the year 2009 as already shown in Fig. 18. This energy carrier is the sector with the highest energy consumption in Europe. The distribution on a percentage basis to the different industry sectors can be seen in Fig. 27. Every industry sector uses electrical energy as an energy carrier for their production. The biggest share has the chemical industry with 20 %. It is followed by the paper and printing industry with 14 % and the iron and steel industry and the food, drink and tobacco industry with each 12 %. Other important industry sectors with high consumption are the machinery industry with 11 %, the glass, pottery and building material industry with 8%, the paper and printing industry with 7 % and the transport equipment with 6 %.

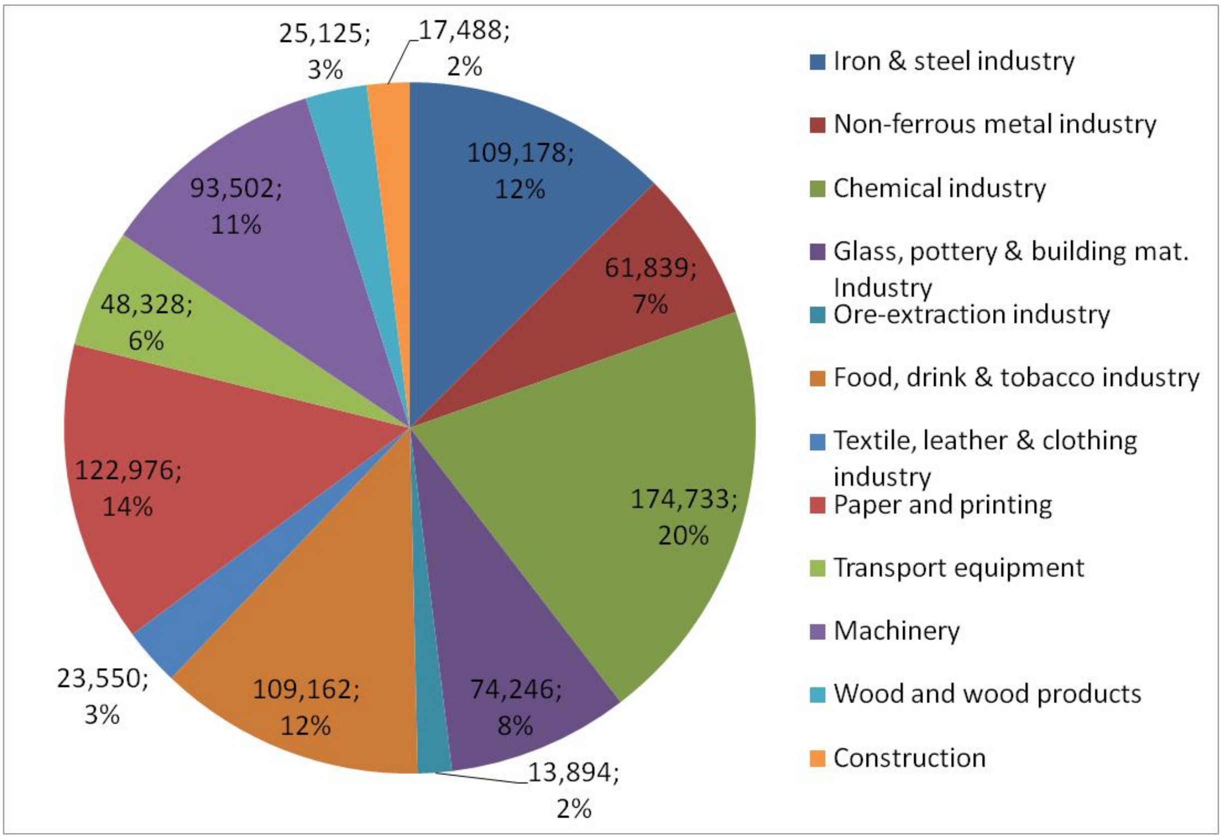

Fig. 27: Final energy consumption in the industry of the EU-27 covered by electrical energy in 2009 (Sum: 980,994 GWh) [3]

4. Case studies for the five most energy-intensive industry sectors in the EU-27

In this chapter the saving potential of primary energy and CO_2 –emissions is calculated for different industrial products. Therefore the five most energy-intensive industry sectors are investigated in detail. These five most energy-intensive industry sectors are:

- Iron & steel industry
- Non-ferrous metal industry
- Chemical industry
- Glass, pottery and building materials
- Paper and printing

Typical products out of every industry sector are investigated in form of case studies. It is assumed that the demands of these products are kept constant until 2050. For every product the demand of final energy, primary energy and CO_2 –emissions is calculated for every year and for three different switching scenarios. Furthermore the integrated savings of final energy, primary energy and CO_2 –emissions are presented. The three different switching scenarios are described in chapter 4.1. In chapter 4.2 the theoretical saving potential of the five most energy-intensive industry sectors is calculated. Afterwards the case studies for these five industry sectors are presented in the chapters 4.3 to 4.7.

4.1 Three different scenarios

In the analysis of the case studies three different switching scenarios will be compared with each other. The first scenario is that there will be no change. This is called “reference scenario”. The second scenario assumes that there will be a linear switching from the current situation to a status with 100% electrical power application. This case is called “linear scenario”. The third instance is that we assume a complete switching inside of five years from 2020 to 2025. Within these five years the share of the electrical power use is linearly increased from the current situation to 100%. This scenario is called “shock scenario”. A graph of the share of electrical power for the three different scenarios is shown in Fig. 28. The graphics with the integrated savings in the chapters 4.2 to 4.7 show the savings for the linear and shock scenario instead of taking the reference scenario.

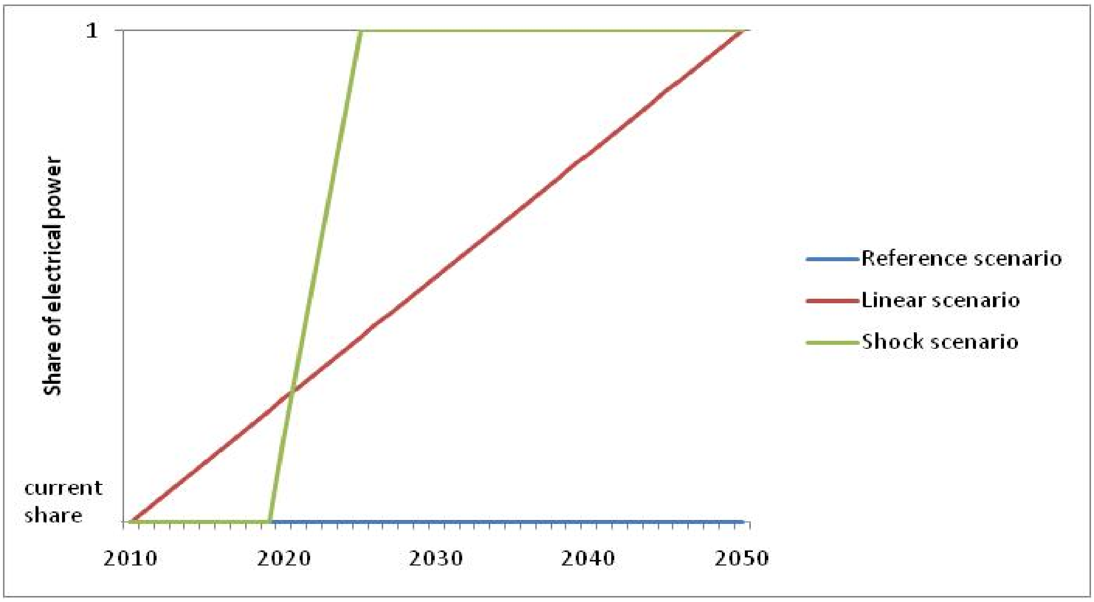

Fig. 28: Share of electrical power for the three different scenarios from the current situation in the year 2010 up to a situation with 100% electrical power in the year 2050

4.2 Theoretical saving potential for the five most energy-intensive industry sectors of the EU-27

In this chapter the theoretical saving potential is analyzed. Therefore it is assumed that all processes of the five most energy-intensive industry sectors will be replaced by electrical processes for 100 %. In the following pictures the cumulative savings of primary energy and CO_2 –emissions for these industry sectors are shown.

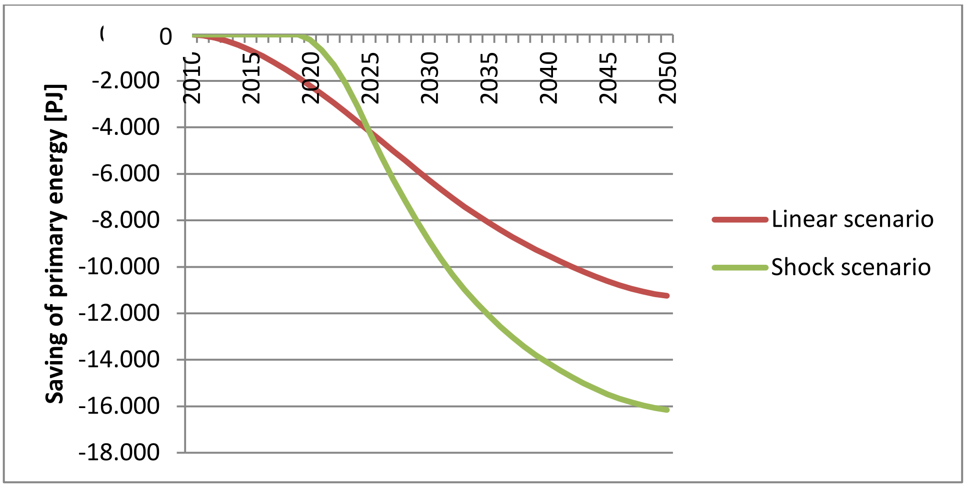

Fig. 29: Theoretical cumulative savings potential of primary energy for selected processes in the iron & steel industry sector of the EU-27

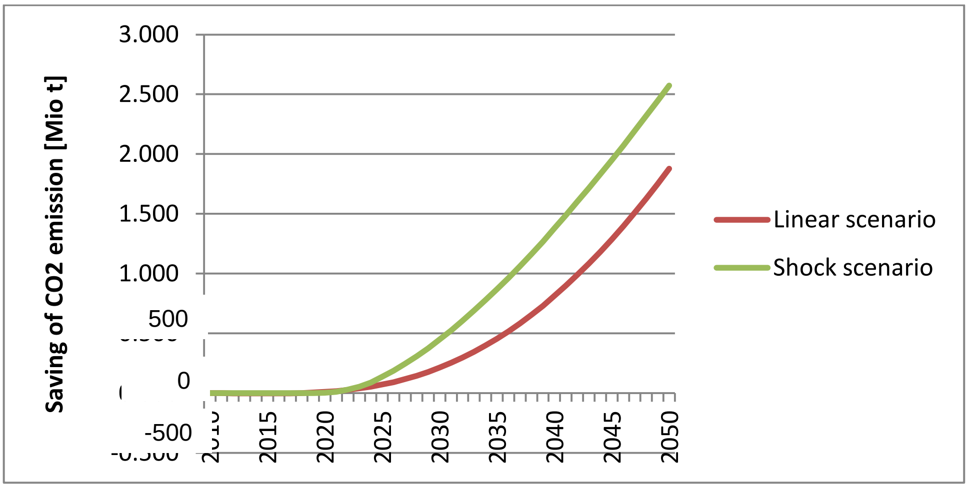

Fig. 30: Theoretical cumulative savings potential of CO2-emissions for selected processes in the iron & steel industry sector of the EU-27

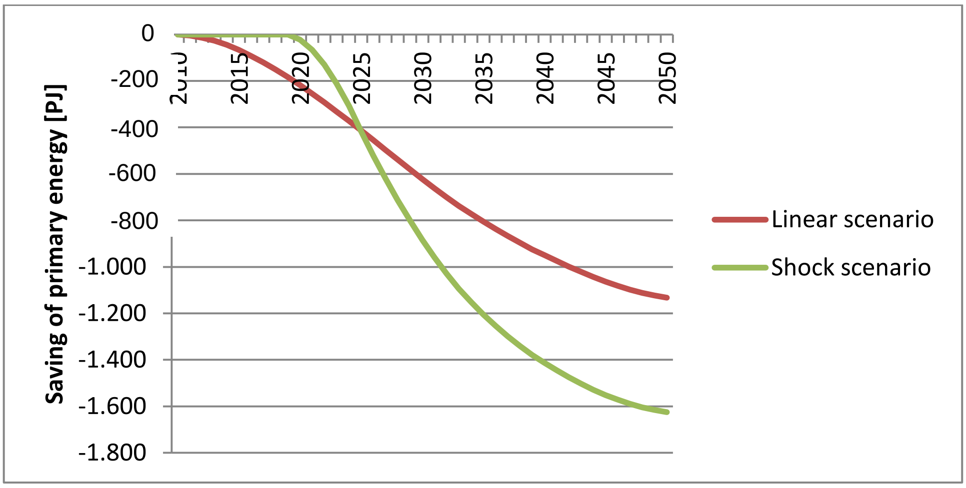

Fig. 31: Theoretical cumulative savings potential of primary energy for selected processes in the non-ferrous metal industry sector of the EU-27

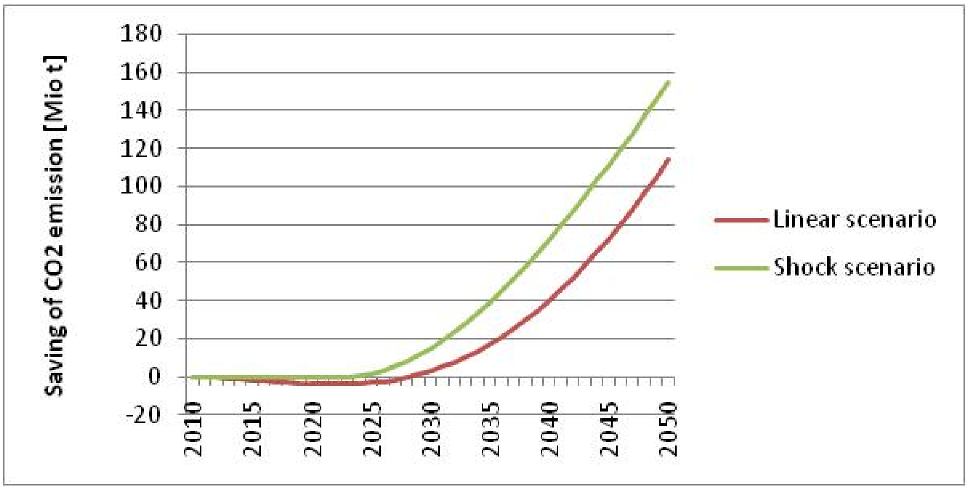

Fig. 32: Theoretical cumulative savings potential of CO2-emissions for selected processes in the non-ferrous metal industry sector of the EU-27

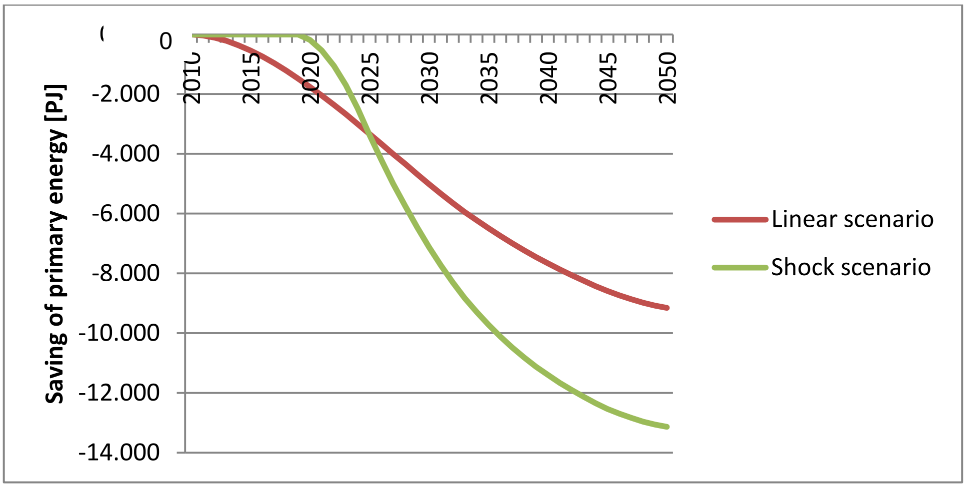

Fig. 33: Theoretical cumulative savings potential of primary energy for selected processes in the chemical industry sector of the EU-27

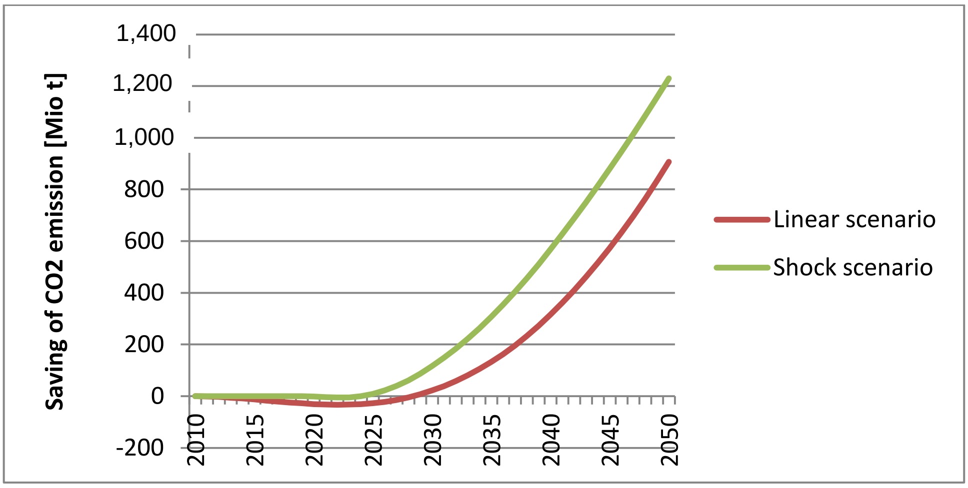

Fig. 34: Theoretical cumulative savings potential of CO2-emissions for selected processes in the chemical industry sector of the EU-27

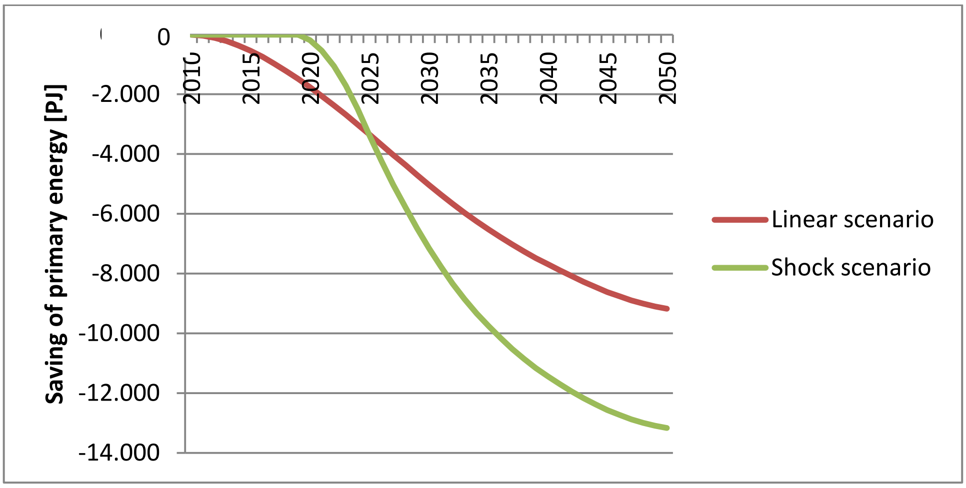

Fig. 35: Theoretical cumulative savings potential of primary energy for selected processes in the glass, pottery and building materials industry sector of the EU-27

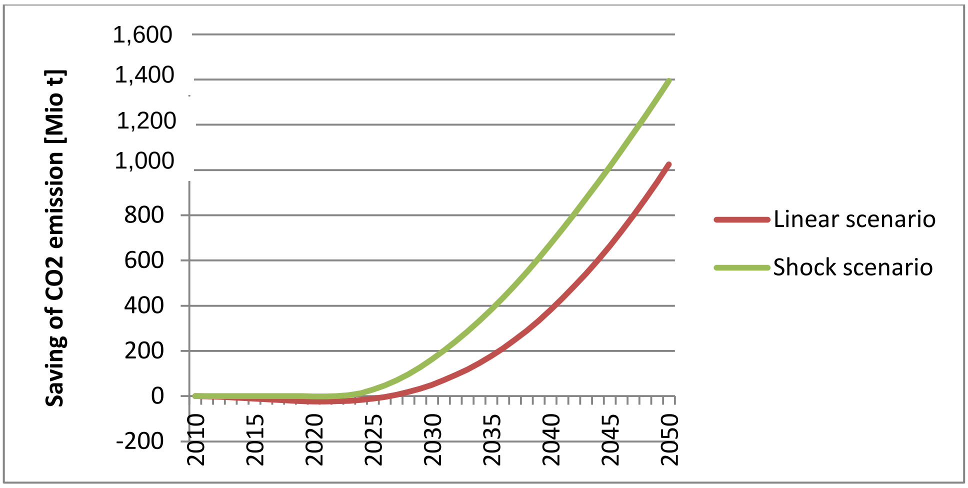

Fig. 36: Theoretical cumulative savings potential of CO2-emissions for selected processes in the glass, pottery and building materials industry sector of the EU-27

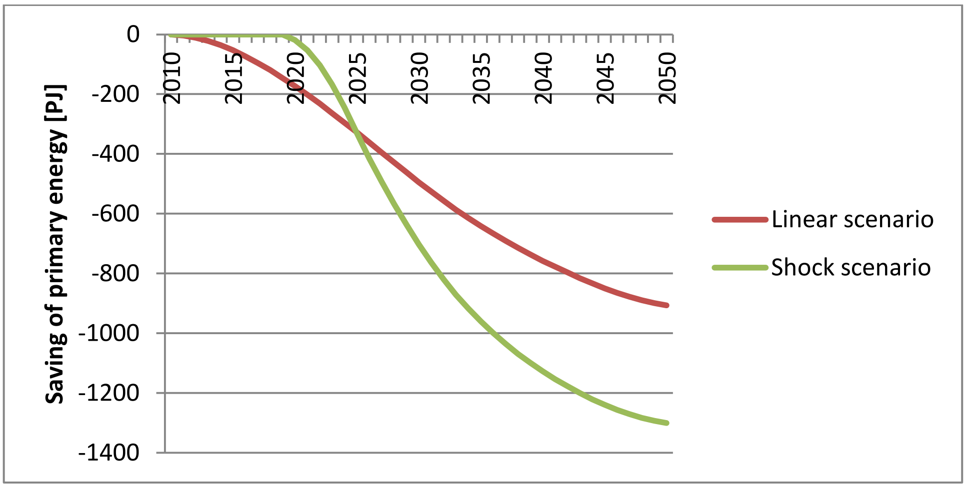

Fig. 37: Theoretical cumulative savings potential of primary energy for selected processes in the paper and printing industry sector of the EU-27

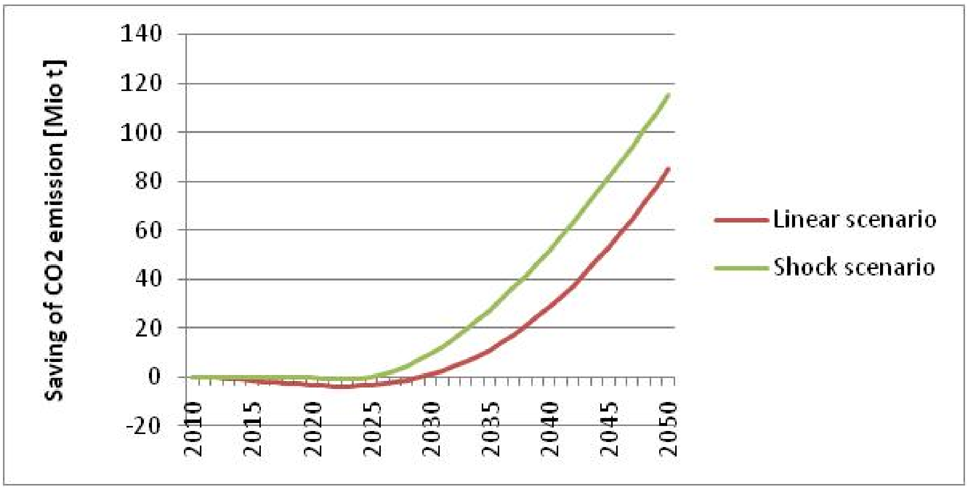

Fig. 38: Theoretical cumulative savings potential of CO2-emissions for selected processes in the paper and printing industry sector of the EU-27

4.3 Iron & steel industry

4.3.1 Steel production

In the year 2009 the 27 European states produced more than 139 Million tons of steel[4]. It is assumed that the total demand of steel per year in Europe will be constant until 2050. In principle there exist two ways for the production of steel in Europe. The first is the production of crude iron in a blast furnace that is subsequently transformed into steel using an oxygen blown converter. This is the classical route of steel production and has a share of 56 % on the over-all output4. The second technique is the production of steel in furnaces operated with electrical power, especially electric arc furnaces. This furnace can be operated with steel scrap as well as with direct reduced iron. The share of the electric arc furnace on the cumulated steel production is about 44 %4.

The feedstock for the blast furnace is iron ore that is reduced to iron with the help of coke and lime. This is a very energy intensive process. For the fabrication of 1 ton of crude iron a typical blast furnace needs 650 kg of iron ore and 907 kg of sinter. Additionally 475 kg of coke, 800 MJ of electrical energy and 2.5 kg of scrap are used[5]. 18 % of the blast furnace gas is recovered for the production of coke5. Directly after the furnace process the liquid iron is transformed into steel in an oxygen blown converter. Nearly pure oxygen is pumped through the melt to reduce the high amount of carbon inside the volume. The oxygen converter needs for 1 ton of steel approx. 925 kg of raw iron, 50 m^3 of oxygen and 220 kg of scrap to cool down the melt during the process[6].

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[4] **World Steel Association (worldsteel). July 2011.** *Steel Statistical Yearbook 2011.* Brussels : s.n., July 2011.

[5] **K., Wegener-Giebel. 1996.** Bewertung des Energiebedarfs und der CO2-Emission konkurrierender Verfahren zur Eisen- und Stahlproduktion. *Diplomarbeit.* Universität Hannover : s.n., 1996.

[6] **Fraunhofer-Institut für Systemtechnik und Innovationsforschung ISI. August 2004.** *Werkstoffeffizienz - Einsparpotenziale bei Herstellung und Verwendung energieintensiver Grundstoffe.* s.l. : Fraunhofer IRB Verlag, August 2004.

The electric arc furnace is charged with scrap or optional with direct reduced ore. The volume is melted down through a powerful electric arc that is burning between the carbon electrodes and the charged material. For the production of 1 ton of steel the arc furnace has to be filled with approx. 1080 kg of raw material. The melting process requires additionally 1500 MJ of electrical energy, 30 m^3 oxygen, 14 kg coke and 38 kg lime5. At the moment almost all electric arc furnaces in Europe are operating with steel scrap as the charged material.

In order to save carbon emissions in Europe it is reasonable to switch the steel production from the current situation to a new situation, where no blast furnaces are in operation anymore. In order to reach this aim the whole European steel production has to be done by electric furnaces. Assuming that the amount of steel scrap available cannot be increased significantly, the production of direct reduced ore has to be enlarged. At the moment only 0.5 million tons of this material are produced in Europe[4]. Therefore the production of direct reduced iron has to be increased significant. For the production of 1 ton of direct reduced iron approx. 1,500 kg ore, 376 m^3 of natural gas and 486 MJ of electrical power is need in average in Europe5.

Fig. 39 shows the final energy demand of the steel industry for the three different switching scenarios. In Fig. 40 the integrated savings of final energy is demonstrated. It shows the savings for taking the linear and the shock scenario compared with the reference scenario. By taking the reference scenario the savings would be zero. Fig. 41 displays the associated primary energy of the steel industry. This energy is calculated from the final energy with the use of the corresponding primary energy factors described in the paragraph above. Fig. 42 demonstrates the potentials of savings of primary energy that can be obtained by using the linear or shock scenario. Fig. 43 displays the progress of the CO_2-emission in the steel industry from 2010 till 2050. This is calculated by using the CO_2-emission factors presented in the text above. Fig. 44 shows analogous to the pictures before the possible reduction of CO_2-emission depending on the linear or shock scenario.

It becomes obvious that a switching in the steel production from the blast furnace process to the production of direct reduced offers big potentials for saving of primary energy and CO_2-emission. By taking the linear scenario instead of the reference scenario 7.3 million GWh of final energy, 34 million PJ of primary energy and 3.4 billion tons of CO_2-emission can be saved. By using the shock scenario instead of the reference scenario it is possible to save 10 million GWh of final energy, 48 million PJ of primary energy and 4.8 billion tons of CO_2-emission.

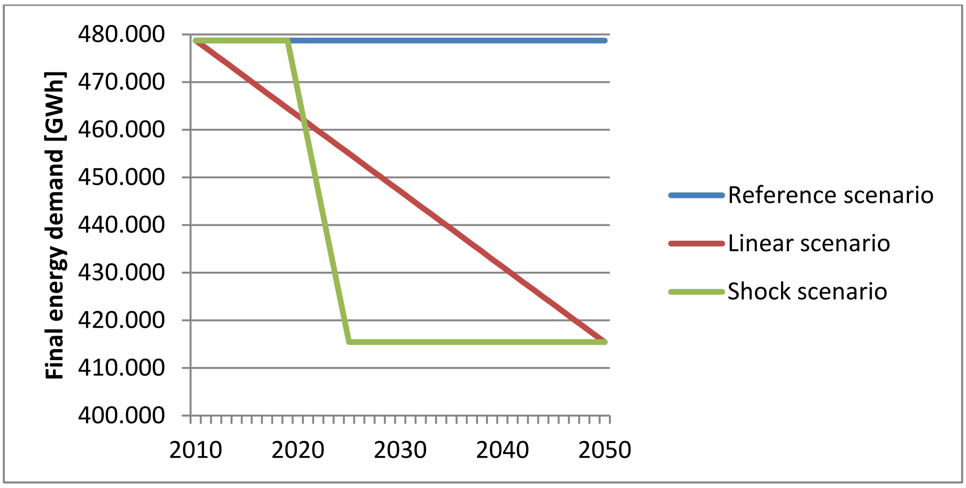

Fig. 39: Final energy demand for producing steel in the EU-27 from 2010 to 2050

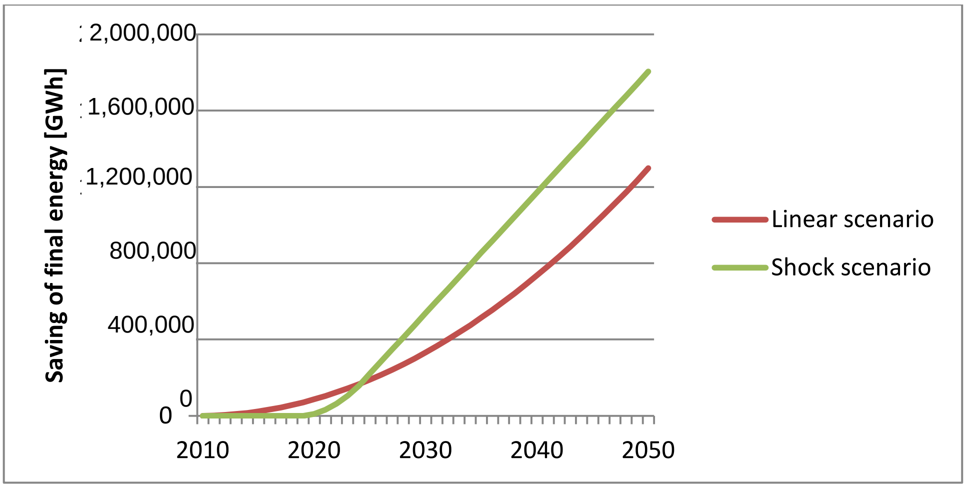

Fig. 40: Saving of final energy for producing steel by using the linear and shock scenario compared of the reference scenario

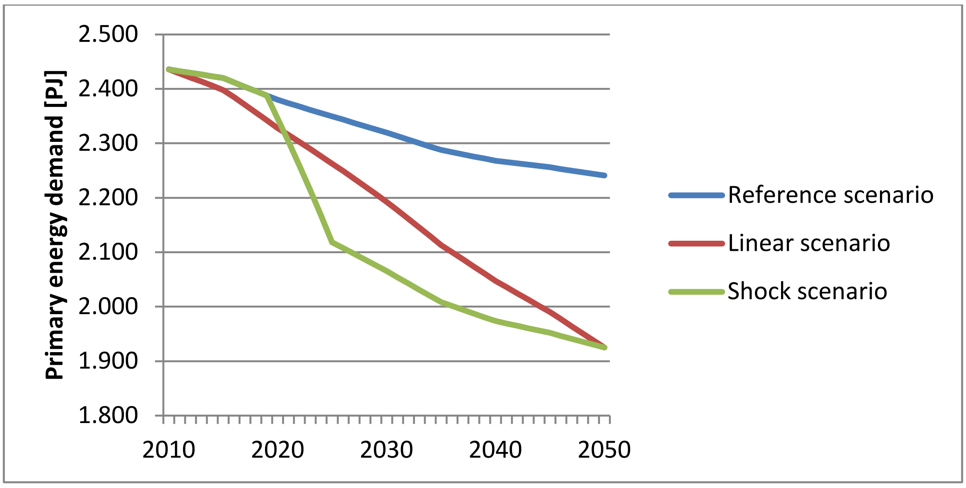

Fig. 41: Primary energy demand for producing steel in the EU-27 from 2010 to 2050

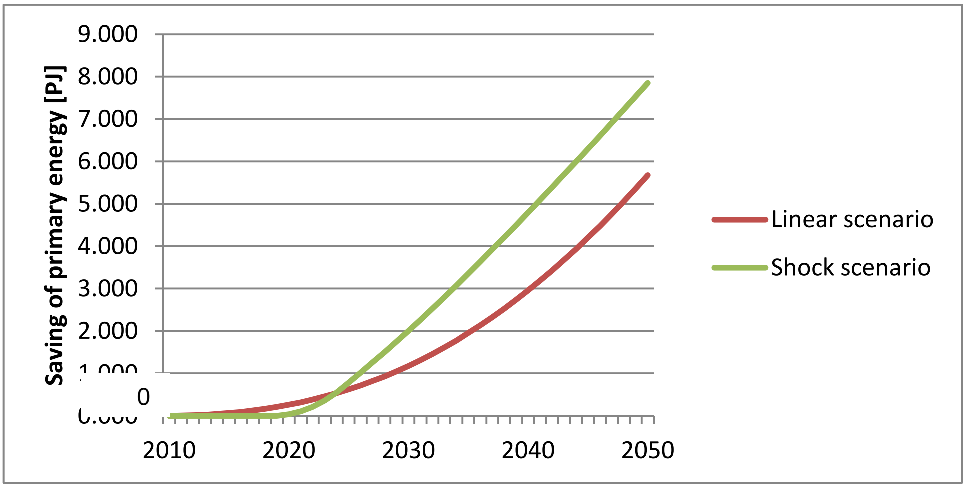

Fig. 42: Saving of primary energy for producing steel by using the linear and shock scenario compared of the reference scenario

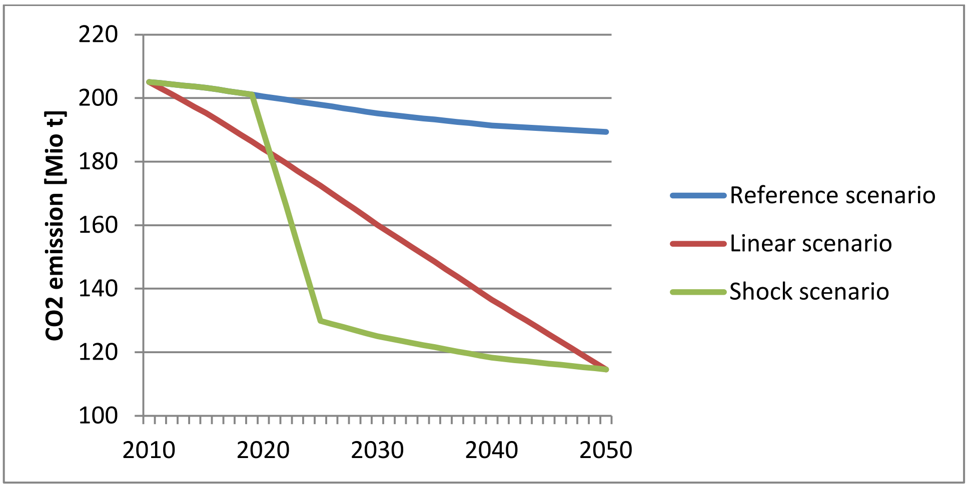

Fig. 43: CO_2-emission for producing steel in the EU-27 from 2010 to 2050

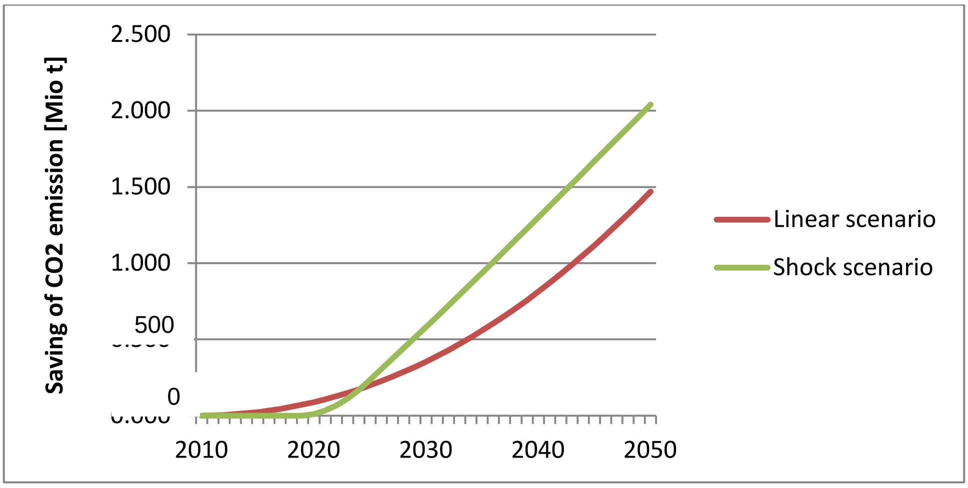

Fig. 44: Saving of CO_2-emission for producing steel by using the linear and shock scenario compared of the reference scenario

4.3.2 Casting grey iron

In the EU-27 in 2007 the yearly production rate of casted grey iron was 13 million tons. For the fabrication of grey iron a couple of different techniques exist. There a three oven types that are used for melting namely cupola furnaces, rotary furnaces and induction furnaces. Each furnace type can be subdivided into some sub-categories which differ in some process parameters. Despite of this great number of processes in the EU-27 mainly only two of them are used. This is the hot blast cupola furnace which is heated with combustibles and the medium frequency induction crucible furnace which is heated with electrical power. The amount of both processes is each approximately 50 % of the total amount of casted grey iron[7].

The melting of iron with the cupola furnace is based on the principle of countervailing influence of a shaft furnace. Iron, coke and lime are continuous filled inside the shaft from above. In the low range of the combustion chamber wind is blown inside to induce the reaction of the coke with the iron. The special feature of the hot blast cupola furnace is the preheating of the wind which increases the efficiency. The used coke is not only the energy supplier for the process but also a reducing agent. With the help of a siphon the grey iron can be drained continuously. This leads to a constant quality level of the product but also to an increase of heat losses. For the production of 1 ton of grey iron 900 kWh of coke, 20 kWh of gas and 30 kWh of electrical power are needed. Additional 143 kWh are needed for the compensation of the fire losses7.

The induction crucible furnace is based on a completely different principle of operation. The induction crucible furnace is based on the mechanisms of the induction effect. The used frequency of the medium frequency induction crucible furnace is the range between 150 Hz and 1,000 Hz. For the calculation in this chapter the averaged and also common frequency of 250 Hz is used. The induction crucible has some advantages over the cupola furnace. It is possible to melt low-prized steel scrap. The strong movement of the melt leads to homogenization of the material and by association to a higher quality. The input energy can be controlled

[7] **E. Baake, U. Jörn, A. Mühlbauer. 1996.** *Energiebedarf und CO2-Emission industrieller Prozeßwärmeverfahren.* Essen : VULKAN VERLAG, 1996. 3-8027-2912-9.

precisely and automated. This leads to a good temperature control inside the crucible. For the production of 1 ton of grey iron 520 kWh of electrical power are needed. Additional 48 kWh are needed for the compensation of the fire losses and 74 kWh for the carburization7.

Taking the above numbers into account, the production of 13 million tons of grey iron consumes 11,000 GWh. It has saving potentials for energy and CO_2-emission. The use of final energy, primary energy, CO_2-emission and the integrated savings can be seen in the following figures. By taking the linear scenario instead of the reference scenario 53,833 GWh of final energy, 135.6 PJ of primary energy and 48.1 million tons of CO_2-emission can be saved. By using the shock scenario instead of the reference scenario it is possible to save 74,841 GWh of final energy, 184.5 PJ of primary energy and 66.6 million tons of CO_2-emission.

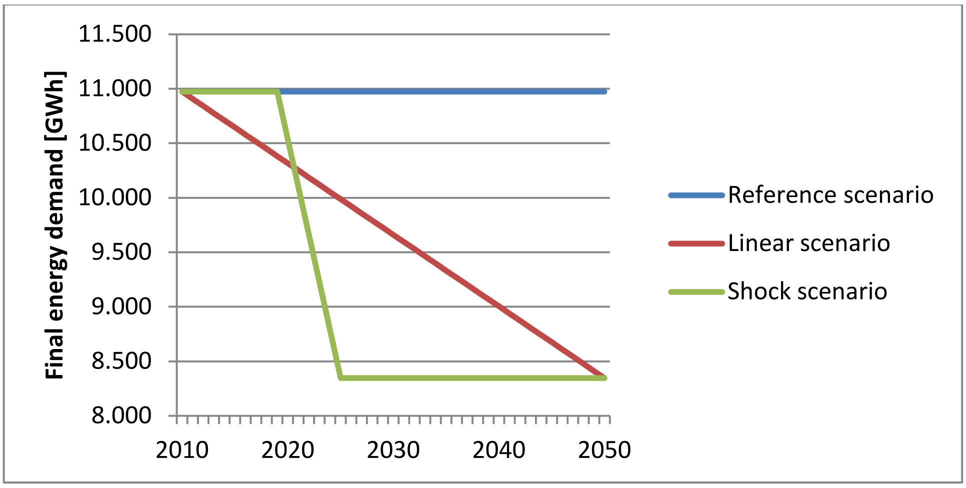

Fig. 45: Final energy demand for casting grey iron from 2010 to 2050

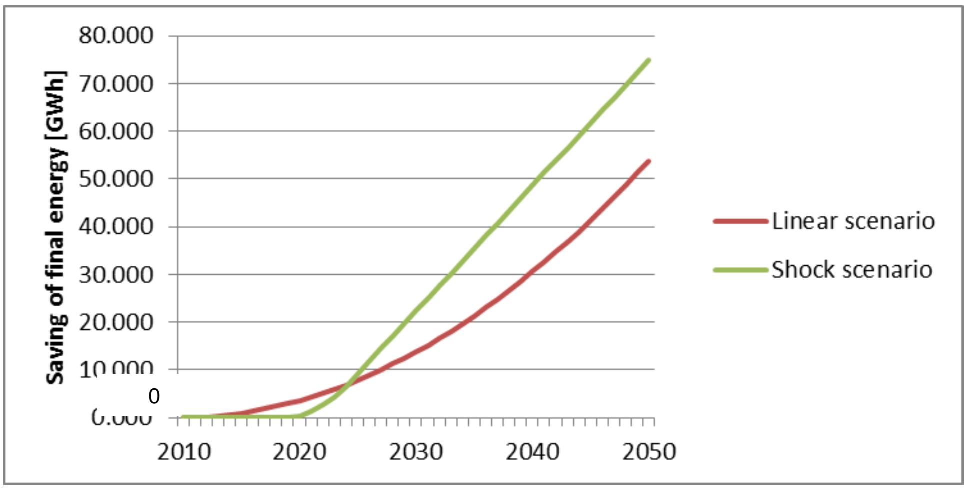

Fig. 46: Saving of final energy for casting grey iron by using the linear and shock scenario compared of the reference scenario

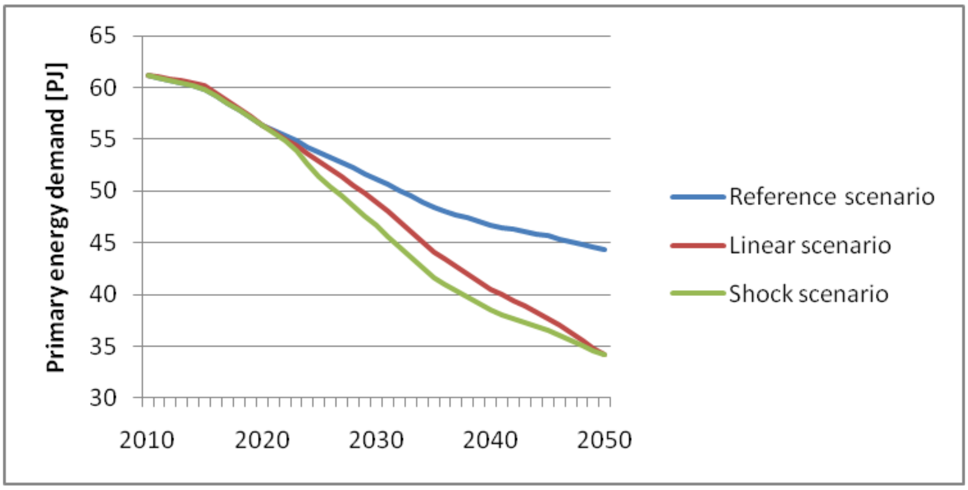

Fig. 47: Primary energy demand for casting grey iron from 2010 to 2050

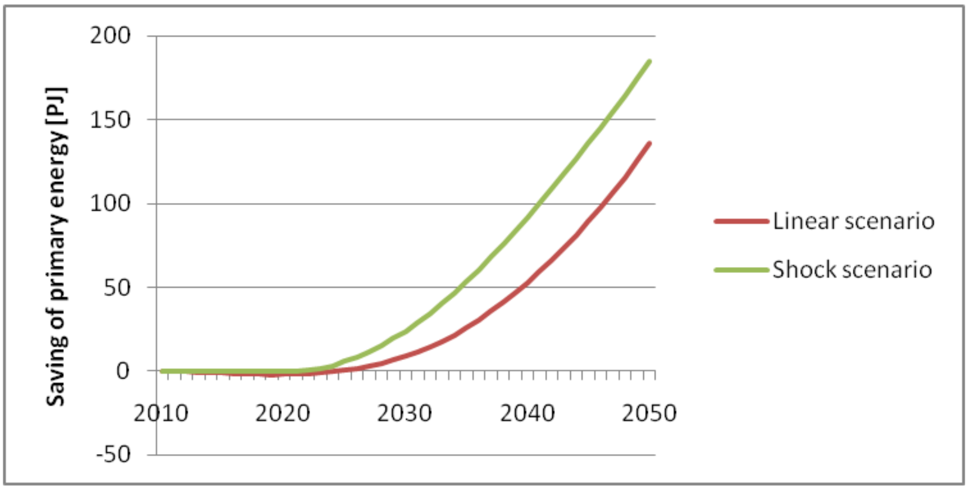

Fig. 48: Saving of primary energy for casting grey iron by using the linear and shock scenario compared of the reference scenario

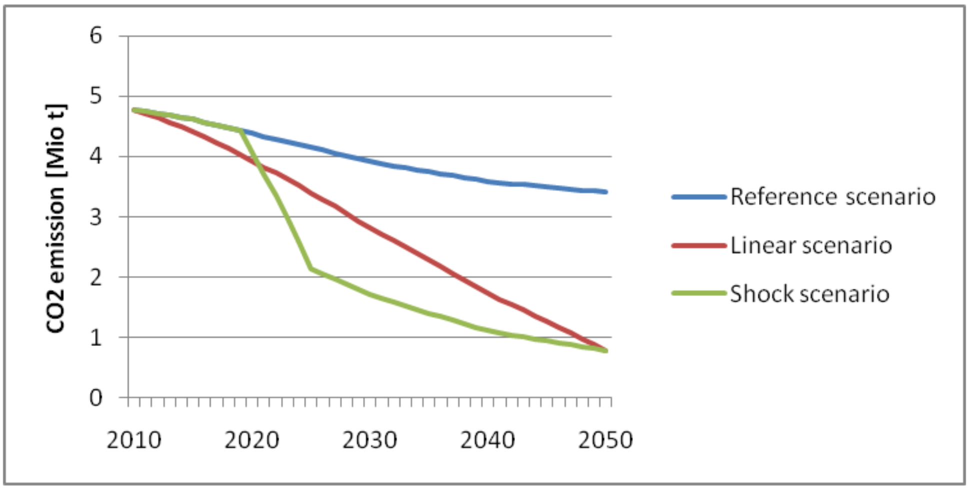

Fig. 49: CO2 emission for casting grey iron from 2010 to 2050

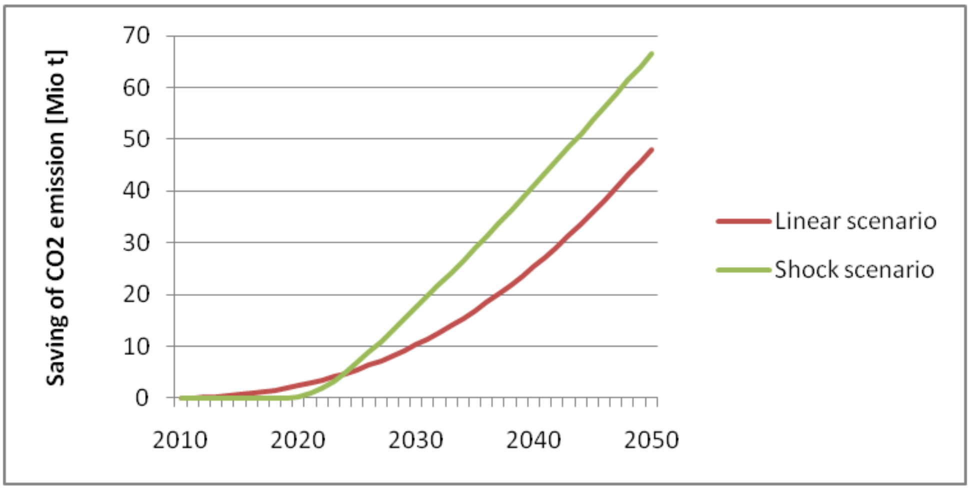

Fig. 50: Saving of CO2 emission for casting grey iron by using the linear and shock scenario compared of the reference scenario

4.4 Non-ferrous metal industry

4.4.1 Casting copper

In the EU-27 in 2009 the yearly production rate of casted copper and copper-based alloys was 158 thousand tons[8]. Compared to the aluminum production this is a relatively small number. Discussions with some branch experts concluded that approximately 70 – 90 % of the overall casted copper production was covered by electro-thermal processes. Especially induction channel furnaces are used to cast copper. The reason is the relatively high efficiency of induction channel furnaces. Induction crucible furnaces are frequently used for copper alloys, because they can be used in batch mode. This is necessary to adjust the correct proportion between the supplied raw materials. Due to the relatively low installed capacities of fuel operated processes a switching scenario for the copper production wouldn't provide further findings.

[8] **Modern Casting. December 2010.** 44th Census of World Casting Production. December 2010.

4.4.2 Casting aluminum

In the EU-27 in 2009 the yearly production rate of casted aluminum was 1.96 million tons[8]. Approximately 8 % of the overall production was covered by electro-thermal processes and 92 % by fuel operated processes[9]. The electro-thermal processes can be divided into induction crucible furnaces and induction channel furnaces. The induction channel furnace is the more common process. A typical induction channel furnace with an oven capacity of 55 tons needs approximately 415 kWh of electrical energy[7]. To replace the fire losses of the aluminum about 200 kWh of electrical energy is used[7]. The fuel operated furnaces are mostly rotary furnaces that have a capacity of about 35 tons[7]. They are operated with natural gas and have an energy consumption of approximately 712 kWh[7]. The fire losses are taken into account with 775 kWh[7]. These losses are much higher than for the electro-thermal processes.

The use of final energy, primary energy, CO_2-emission and the integrated savings can be seen in the following figures.The production of aluminium has both saving potentials for energy and CO_2-emission. By taking the linear scenario instead of the reference scenario 32,126.7 GWh of final energy, 104.9 PJ of primary energy and 13.2 million tons of CO_2-emission can be saved. By using the shock scenario instead of the reference scenario it is possible to save 44,677.9 GWh of final energy, 144.8 PJ of primary energy and 18.3 million tons of CO_2-emission.

[9] **Vereinigung Deutscher Schmelzhütten (VDS). 2000.** *Aluminiumrecycling.* Düsseldorf : W.A. Meinke, 2000. 3-00-003839-6.

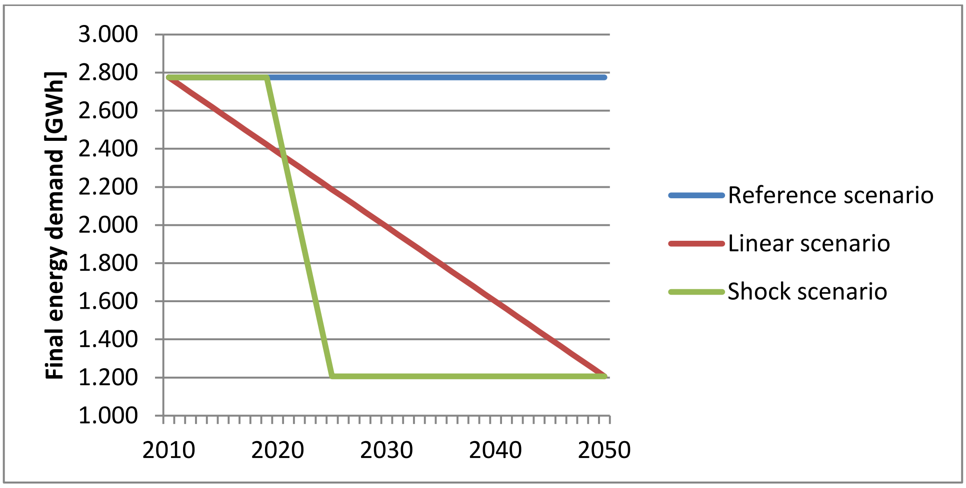

Fig. 51: Final energy demand for casting aluminum from 2010 to 2050

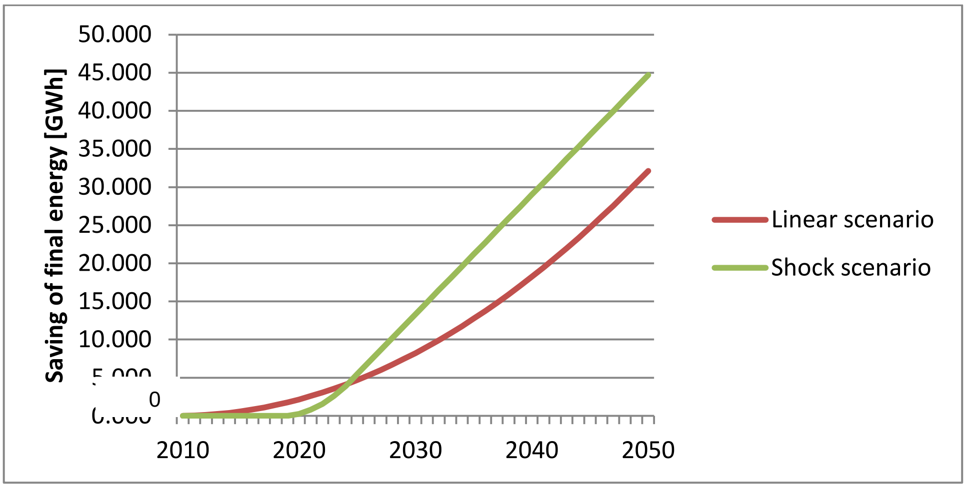

Fig. 52: Saving of final energy for casting aluminum by using the linear and shock scenario compared of the reference scenario

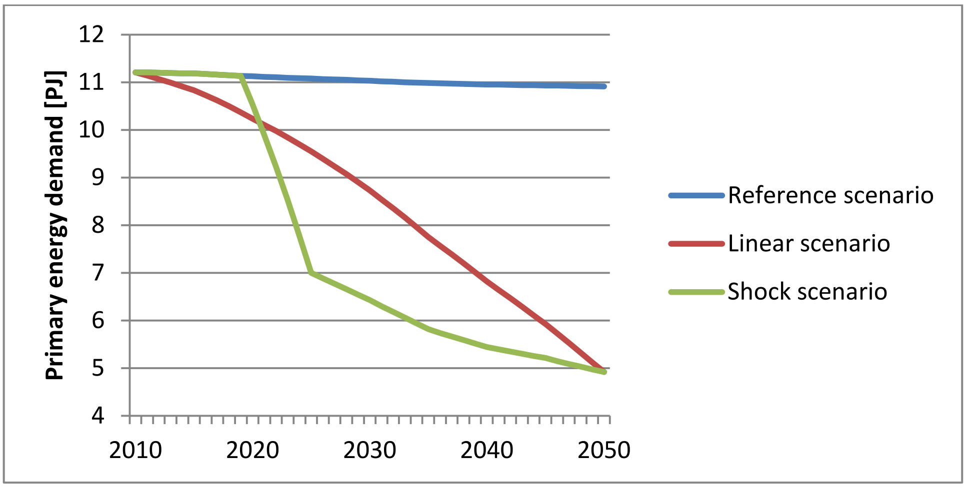

Fig. 53: Primary energy demand for casting aluminum from 2010 to 2050

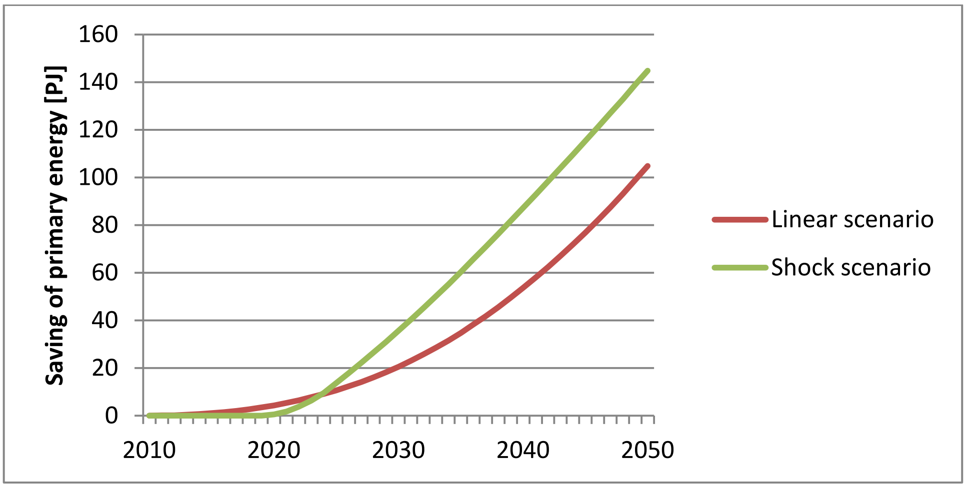

Fig. 54: Saving of primary energy for casting aluminum by using the linear and shock scenario compared of the reference scenario

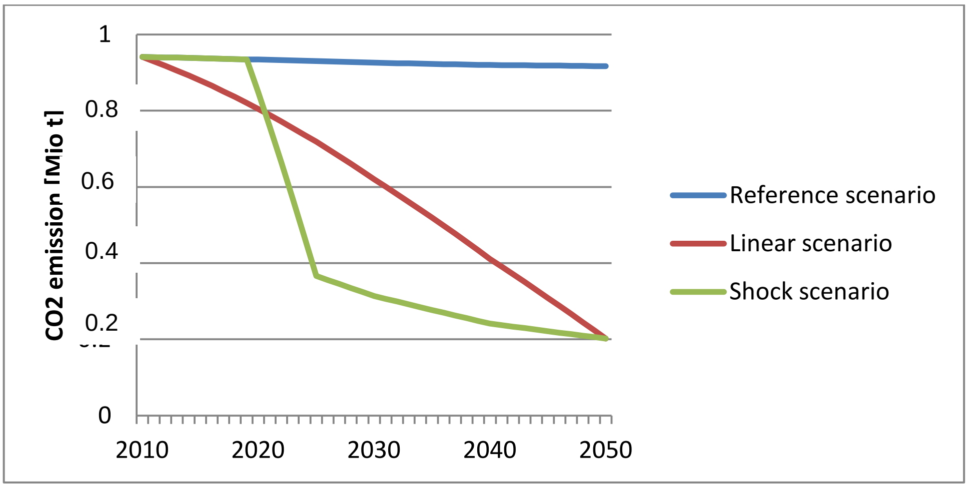

Fig. 55: CO2 emission for casting aluminum from 2010 to 2050

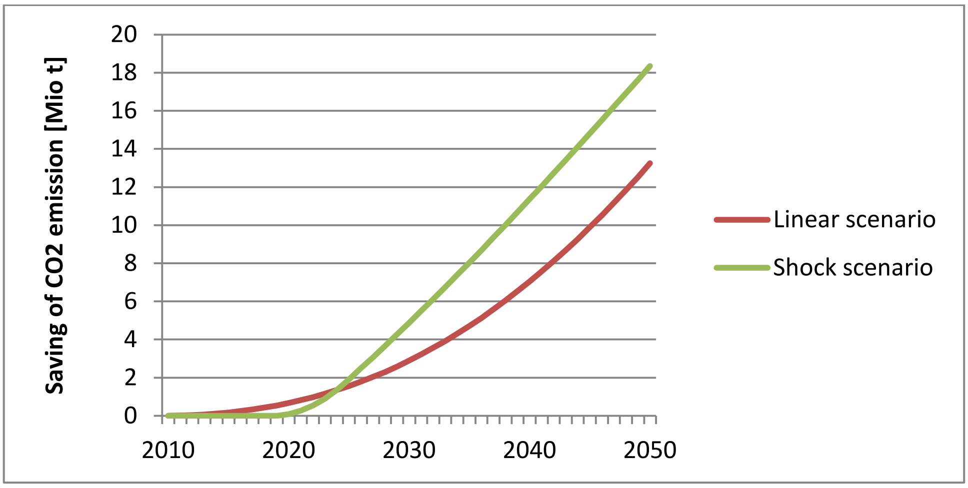

Fig. 56: Saving of CO2 emission for casting aluminum by using the linear and shock scenario compared of the reference scenario

4.5 Chemical industry

4.5.1 Plastic production

In the EU-27 in 2007 the yearly plastic production rate was 65 million tons[10]. For the fabrication of plastic products mechanical and thermal energy is needed. Mechanical energy is used for transport processes, for mixing and grinding and for filling and wrapping applications. Thermal energy is used in large amounts for all kinds of plastic productions. This heat is mostly produced by electrical energy. In addition thermal energy is used for drying plastic pellets. Thermal energy is also used for process steam, which is needed for the Styrofoam production. In the plastic production the three energy carriers, gas, oil and electrical power are used. In former times also coal has been used but since the year 2000 this stopped. The rate of gas is 30%, oil 9 % and the rate of electrical energy is already 61 %[11]. The specific use of energy for the plastic production is 1.7 MWh/to[12]. This leads to a final energy demand of 110,500 GWh.

The use of final energy, primary energy, CO_2-emission and the integrated savings can be seen in the following figures. The production of plastic has saving potentials of CO_2-emission but needs an additional use of primary energy. By taking the linear scenario instead of the reference scenario 102.6 million tons of CO_2-emission can be saved while 1,245.8 PJ of primary energy has to be used additionally. By using the shock scenario instead of the reference scenario it is possible to save 138.5 million tons of CO_2-emission while 1,787 PJ of primary energy are needed additionally. The demand of final energy remains constant for the whole time period and for all scenarios. Because of this no final energy can be saved.

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[10] **EuPC, EPRO, EuPR and PlasticsEurope. 2008.** Daten und Fakten zu Kunststoff 2007. *Kunststoffproduktion, Verbrauch und Verwertung in Europa 2007.* s.l. : PlasticsEurope, 2008.

[11] **A. Trautmann, J. Meyer, S. Herpertz. 2002.** *Rationelle Energienutzung in der Kunststoff verarbeitenden Industrie.* Braunschweig/Wiesbaden : Vieweg, 2002.

[12] **NRW, Landesinitiative Zukunfsenergien. 2002.** Rationelle Energienutzung in der Kunststoff verarbeitenden Industrie. Düsseldorf : Landesinitiative Zukunfsenergien, 2002.

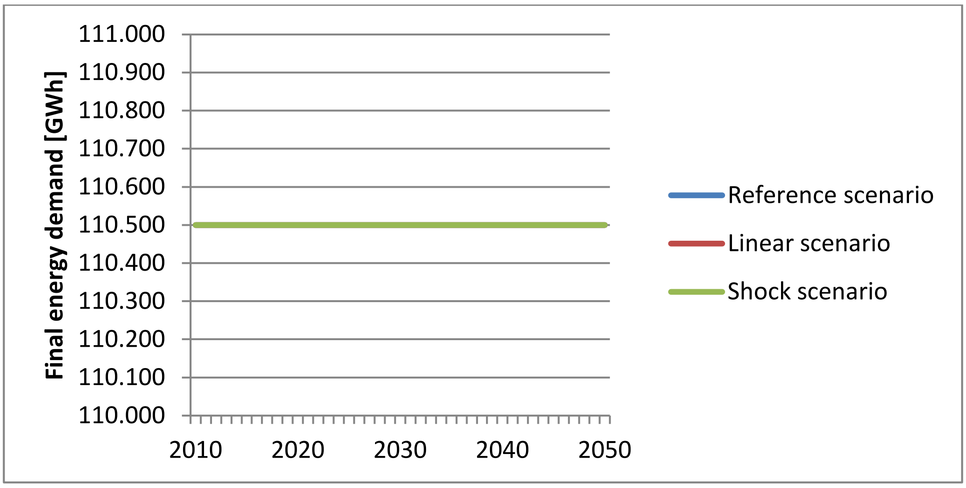

Fig. 57: Final energy demand for producing plastic from 2010 to 2050

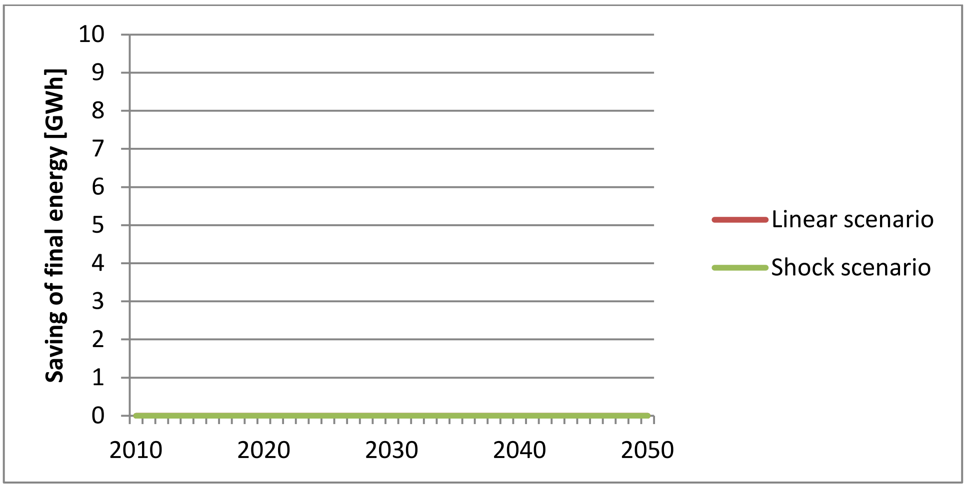

Fig. 58: Saving of final energy for producing plastic by using the linear and shock scenario compared of the reference scenario

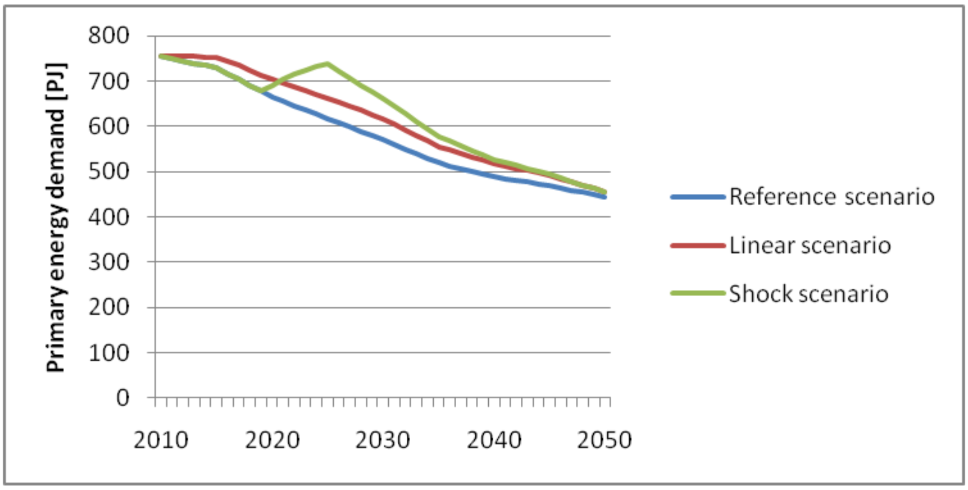

Fig. 59: Primary energy demand for producing plastic from 2010 to 2050

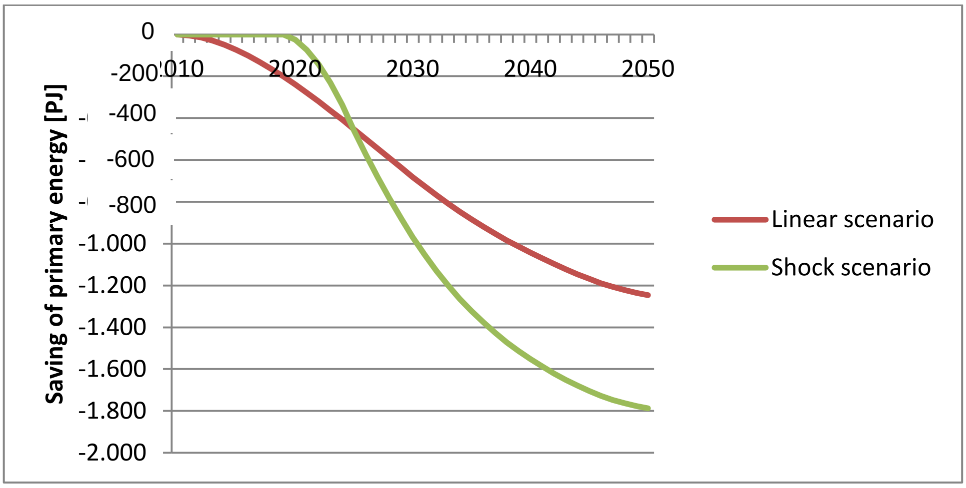

Fig. 60: Saving of primary energy for producing plastic by using the linear and shock scenario compared of the reference scenario

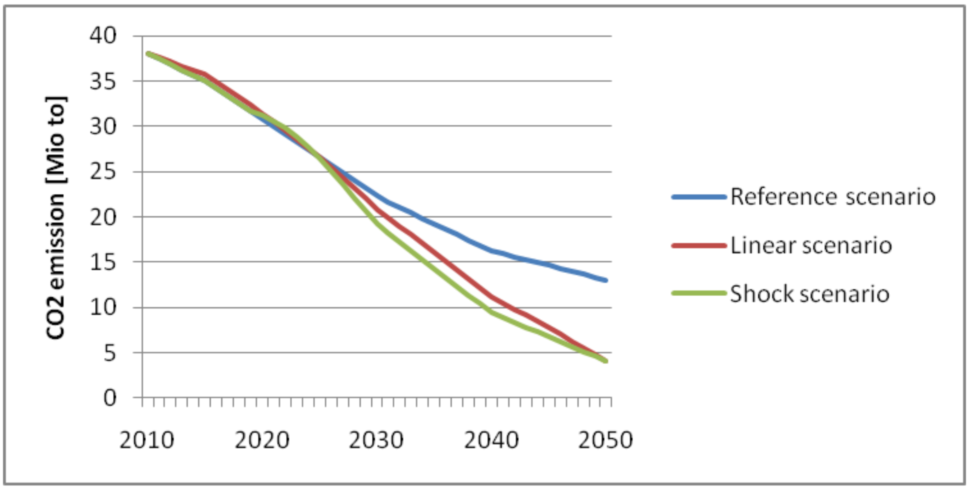

Fig. 61: CO2 emission for producing plastic from 2010 to 2050

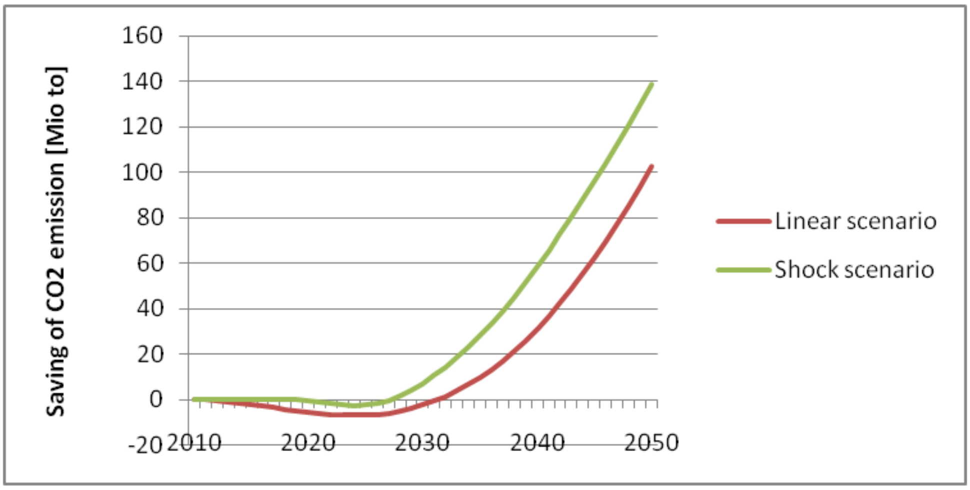

Fig. 62: Saving of CO2 emission for producing plastic by using the linear and shock scenario compared of the reference scenario

4.6 Glass, pottery and building materials

4.6.1 Glass industry

In the EU-27 in 2007 the yearly production rate for glass was 37 million tons[13]. The specific use of energy for the glass production is about 1.5 MWh/to[14]. This leads to a final energy demand of 55.5 TWh. The rate of gas is 34%, oil 46 % and the rate of electrical energy is 20 %[15]. The production of glass can be divided into six steps. They are preparation of the batch, fusing of the batch, contouring, cooling, control of the quality and finishing. For the preparation of the batch the different components of the glass are weighted and mixed. The second step of the process, melting of the batch, is the most energy intensive step, because high temperatures have to be reached. Afterwards the glass is cooled down to contouring temperature to give the glass the final shape. Depending on the application range a large number of different contouring machines are used. The biggest amount of the flat glass production is manufactured with the float procedure. The melt is passed through a zinc bath to obtain a flat and high quality glass. Another important procedure is the fabrication of container or bottle glass which happens in two steps. First the primary form is produced which will be blown up to the end form in the second step. After contouring the glass will be cooled down, controlled in quality and maybe also finished and packed[16].

The use of final energy, primary energy, CO_2-emission and the integrated savings can be seen in the following figures. The production of glass has saving potentials only for CO_2-emission. The use of primary energy will increase for both scenarios. For the linear scenario 128.9 million tons of CO_2-emission can be saved and for the

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[13] **European Comission (EC). 2009.** *Putting Europe´s glass and ceramics industries on the right track.* Brussels : s.n., 2009.

[14] **Glassglobal The glass community. 2009.** *Mehr Energieeffizienz bei der Glasherstellung.* s.l. : VDMA.

[15] **Bayerisches Landesamt für Umweltschutz (LfU) . 1997.** *Anlagenbezogene CO2-Minderungspotentiale in der Glasindustrie.* München : Bay. St. für Landesent. u. Umweltfragen.

[16] Bundesverband Glasindustrie e.V. (BV Glas)

shock scenario 174.9 million tons. Compared with this 1,258.3 PJ of additional primary energy has to be used for the linear scenario and 1,806 PJ of primary energy for the shock scenario. Final energy cannot be saved, because the demand remains constant for the whole time period and for all scenarios.

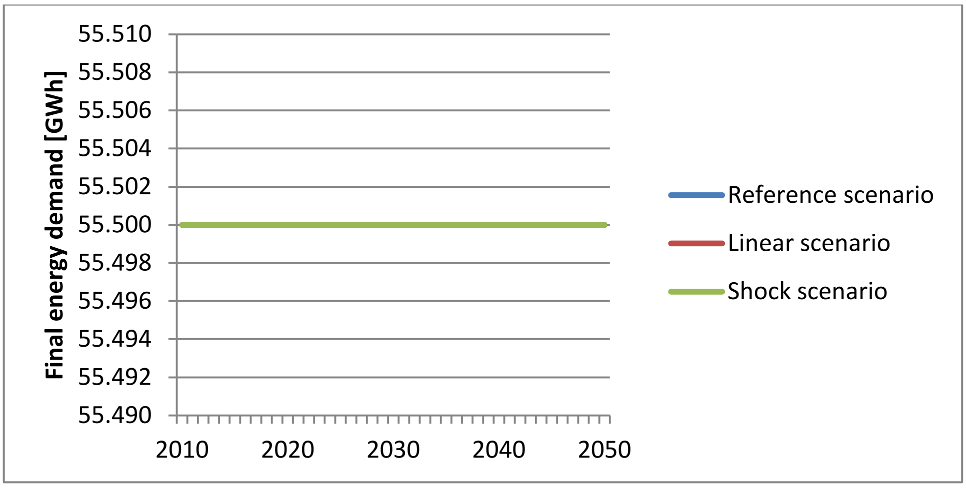

Fig. 63: Final energy demand for producing glass from 2010 to 2050

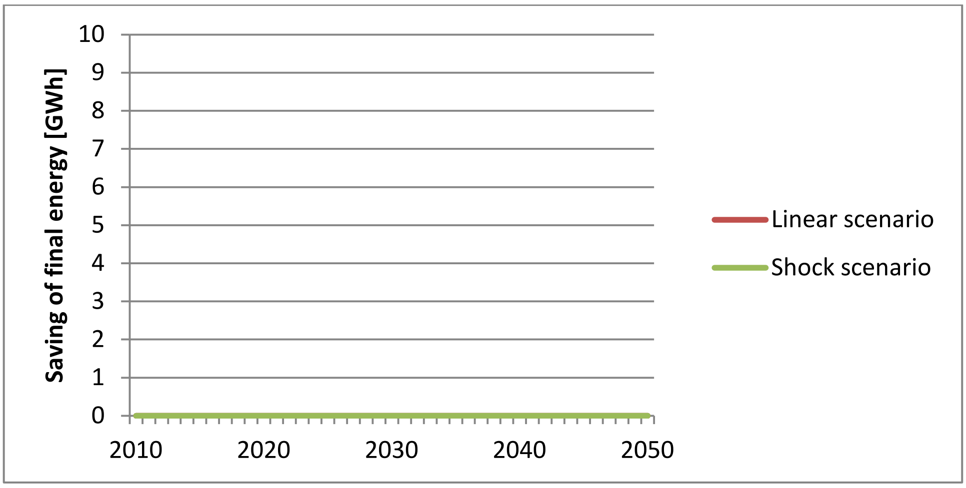

Fig. 64: Saving of final energy for producing glass by using the linear and shock scenario compared of the reference scenario

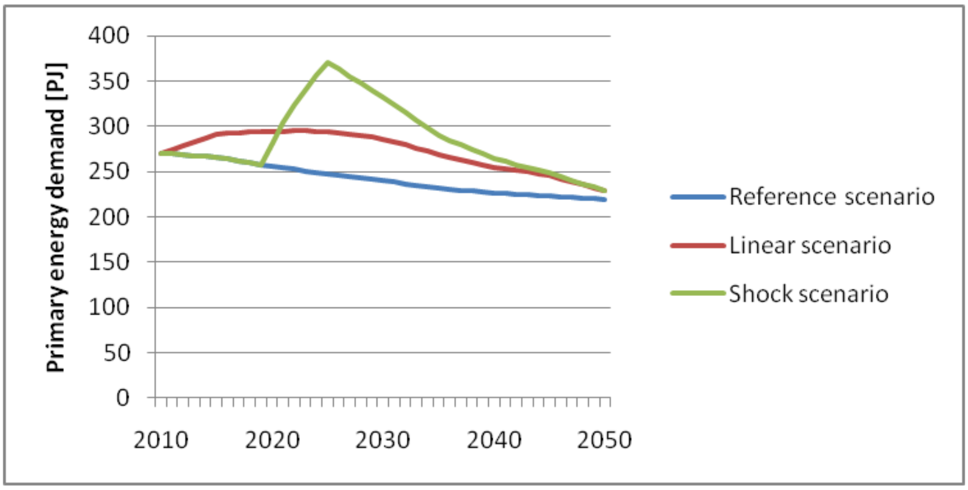

Fig. 65: Primary energy demand for producing glass from 2010 to 2050

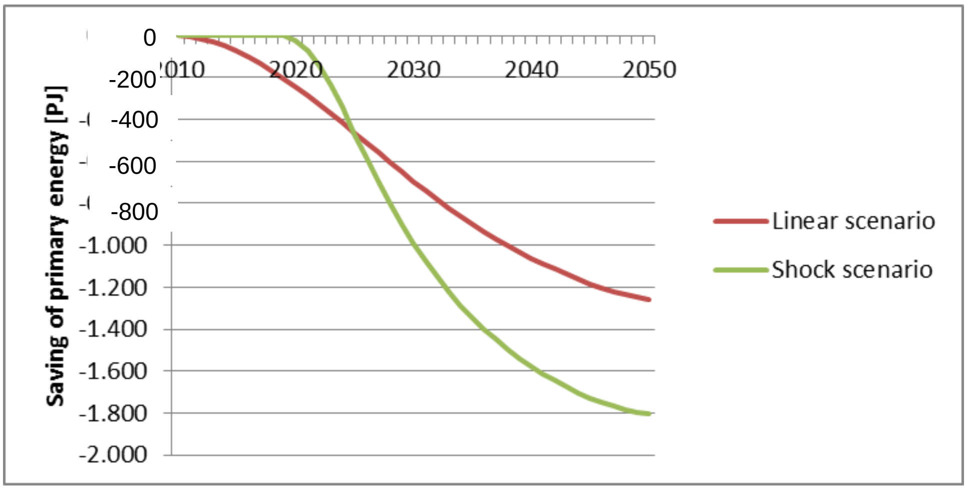

Fig. 66: Saving of primary energy for producing glass by using the linear and shock scenario compared of the reference scenario

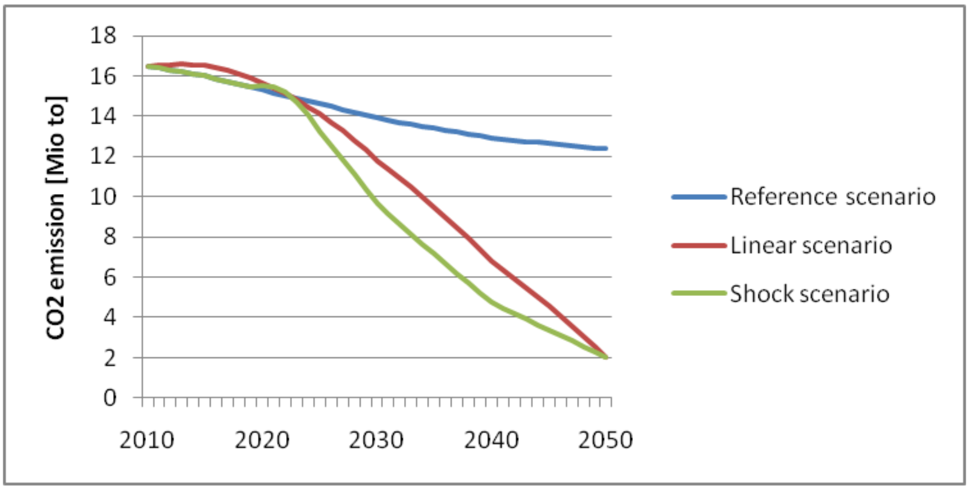

Fig. 67: CO2 emission for producing glass from 2010 to 2050

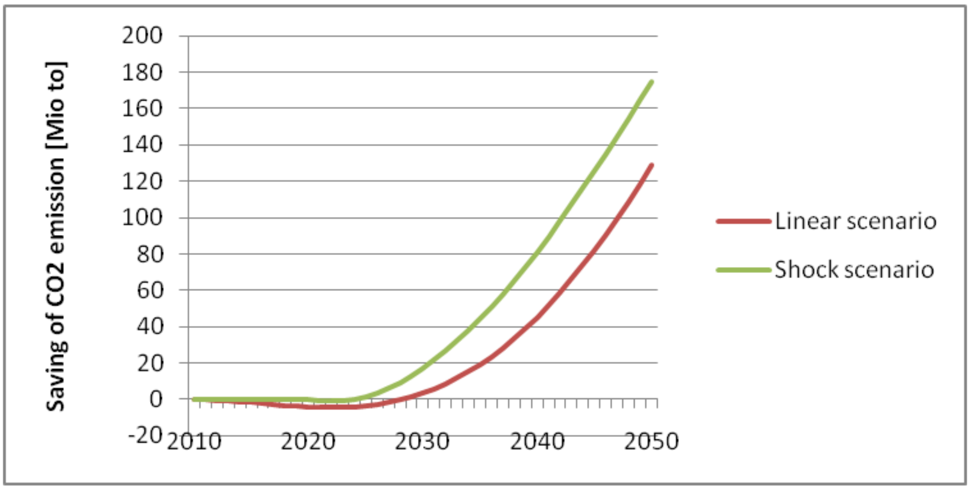

Fig. 68: Saving of final energy for producing glass by using the linear and shock scenario compared of the reference scenario

4.6.2 Brick industry

In the EU-27 the yearly production rate of bricks is about 52.6 million tons[17]. The specific use of energy for the brick production is about 551 kWh/to[18]. This leads to a final energy demand of 28,976 GWh. The rate of gas is 90 %, oil 2 % and the rate of electrical energy is 8 %[18]. In principle bricks consist only of loam and clay. The production process is energy intensive and simple. In the first step clay and loam are grinded and mixed. After that the raw material is pressed in an extruder to an endless line. After cutting into pieces the raw bricks are fired in a tunnel kiln at about 900°C.

The use of final energy, primary energy, CO_2-emission and the integrated savings can be seen in the following figures. The production of bricks has saving potentials of CO_2-emission but needs an additional use of primary energy. By taking the linear scenario instead of the reference scenario 55 million tons of CO_2-emission can be saved while 779.9 PJ of primary energy has to be used additionally. By using the shock scenario instead of the reference scenario it is possible to save 74 million tons of CO_2-emission while 1,118.1 PJ of primary energy are needed additionally. There are no saving possibilities for final energy.

[17] **Tiles and bricks of Europe (TBE). activated in January 2012.** *About TBE.* [Homepage: http://www.tbe-euro.com/default-en.asp] Bruxelles : s.n., activated in January 2012.

[18] **Bayerisches Landesamt für Umweltschutz (LfU). 1998.** *Anlagenbezogene CO2-Minderungspotentiale in der Ziegelindustrie.* München : Bayrisches Landesamt für Landesentwicklung und Umweltfragen, 1998

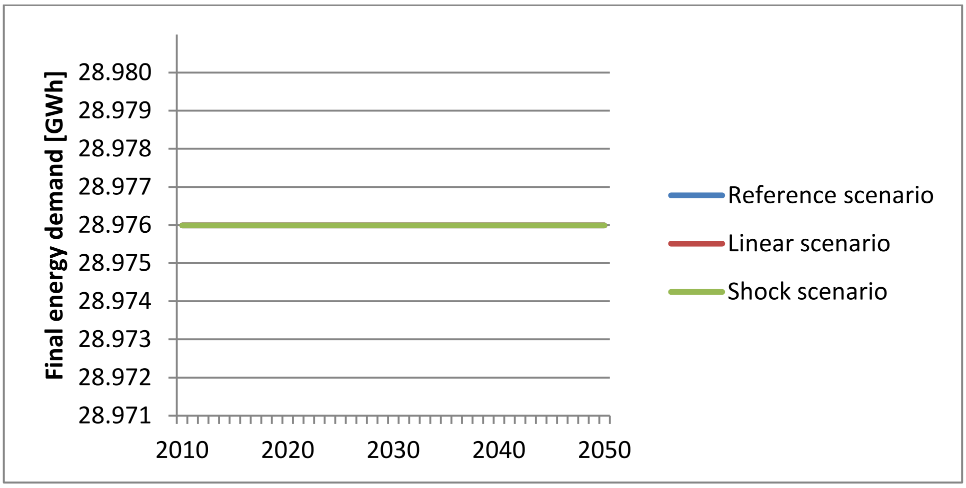

Fig. 69: Final energy demand for producing bricks from 2010 to 2050

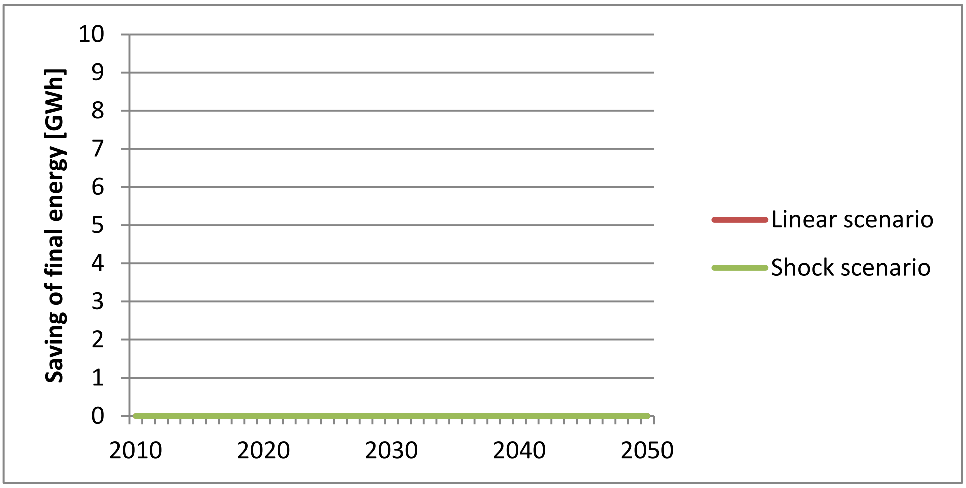

Fig. 70: Saving of final energy for producing bricks by using the linear and shock scenario compared of the reference scenario

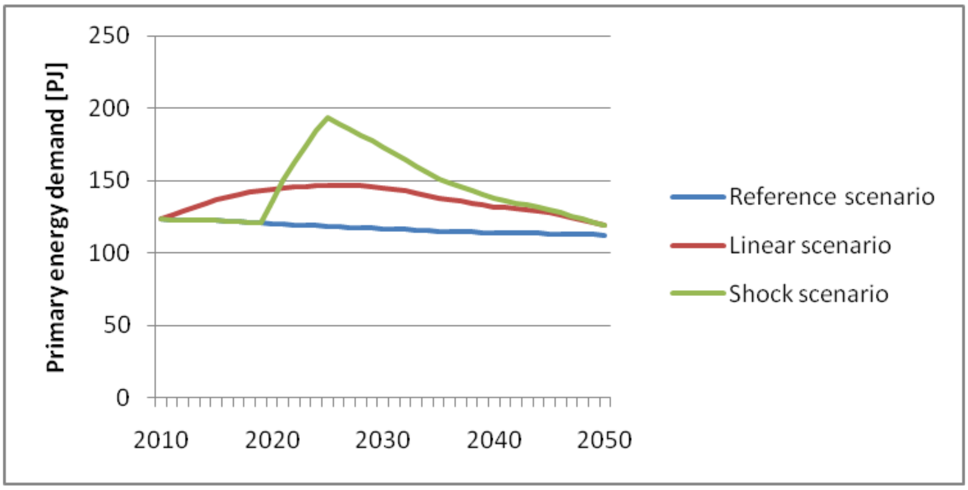

Fig. 71: Primary energy demand for producing bricks from 2010 to 2050

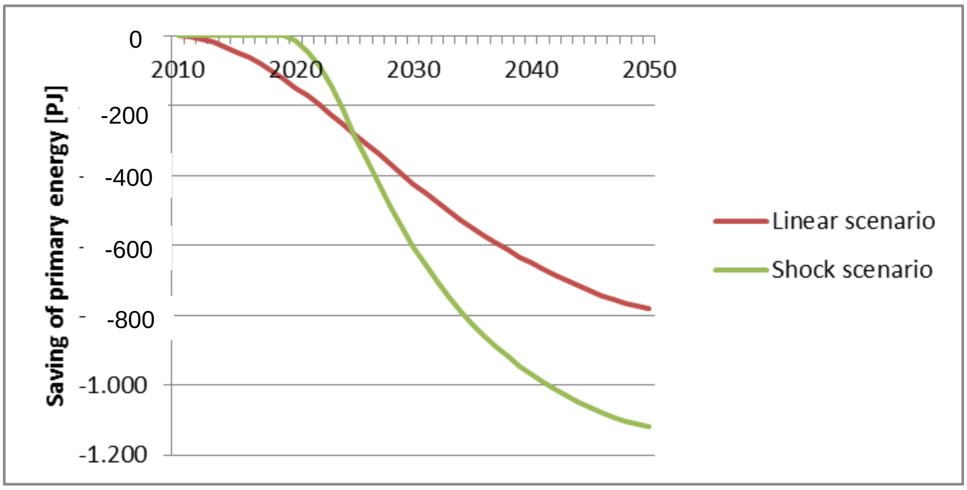

Fig. 72: Saving of primary energy for producing bricks by using the linear and shock scenario compared of the reference scenario

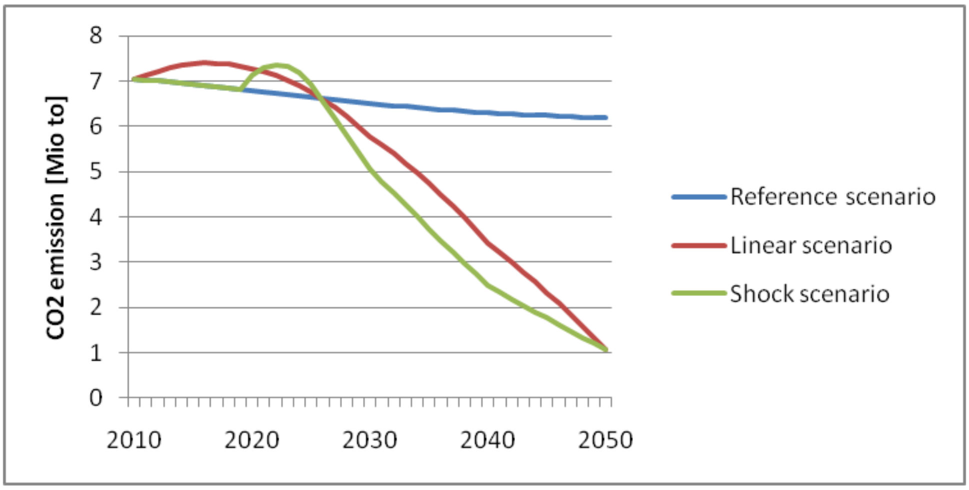

Fig. 73: CO2 emission for producing bricks from 2010 to 2050

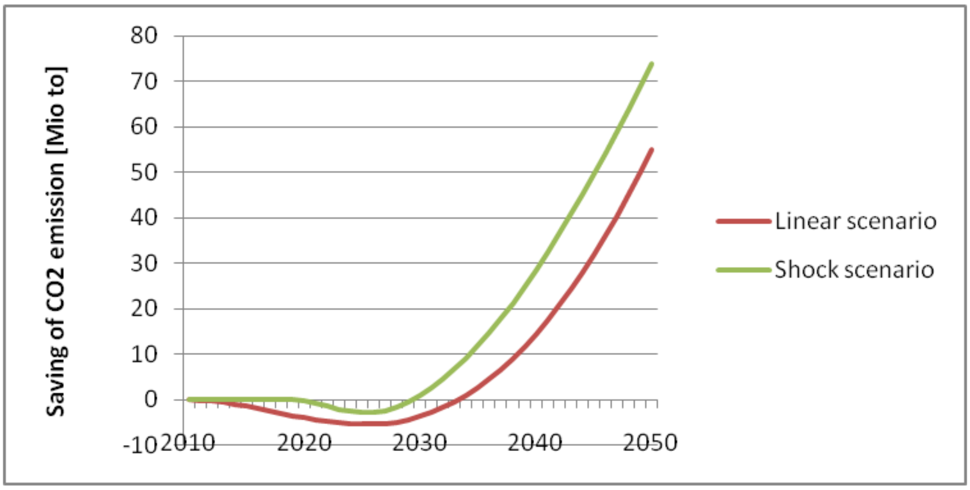

Fig. 74: Saving of final energy for producing bricks by using the linear and shock scenario compared of the reference scenario

4.6.3 Roof tile industry

In the EU-27 in 2009 the yearly production rate for roof tiles was 9.5 million tons[17]. The specific use of energy for the brick production is about 1.105 MWh/to[19]. This leads to a final energy demand of 10,493 GWh. The rate of gas is 90 %, the rate of petroleum products is 0.5 % and the rate of electrical energy is 9.5 %[19]. The production of roof tiles is in principle very similar to the brick production. The material is the same. Only the way of contouring the raw products differs, because most of the roof tiles cannot be formed with an extruder press. This is a reason why roof tiles are a bit more energy intensive than bricks. The burning of the roof tiles in the tunnel kiln is again similar to the brick production.

The use of final energy, primary energy, CO_2-emission and the integrated savings can be seen in the following figures. The production of roof tiles is similar to the brick production in terms of saving possibilities. By taking the linear scenario instead of the reference scenario 19.4 million tons of CO_2-emission can be saved while 278 PJ of primary energy has to be used additionally. By using the shock scenario instead of the reference scenario it is possible to save 26 million tons of CO_2-emission while 398.7 PJ of primary energy are needed additionally. There are no saving possibilities for final energy.

[19] **Bayerisches Landesamt für Umweltschutz (LfU). 1998.** *Anlagenbezogene CO2-Minderungspotentiale bei der Dachziegelherstellung.* München : Bayerisches Staatsministerium für Landesentwicklung und Umweltfragen, 1998.

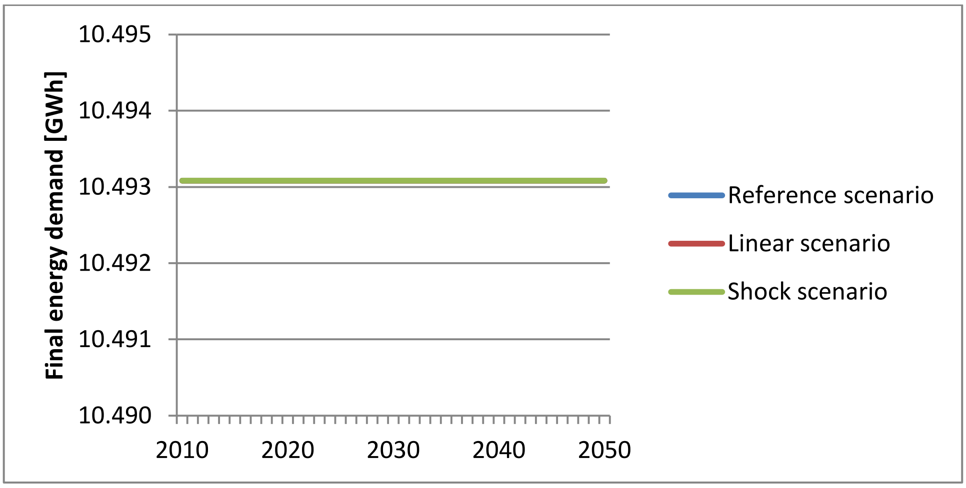

Fig. 75: Final energy demand for producing roof tiles from 2010 to 2050

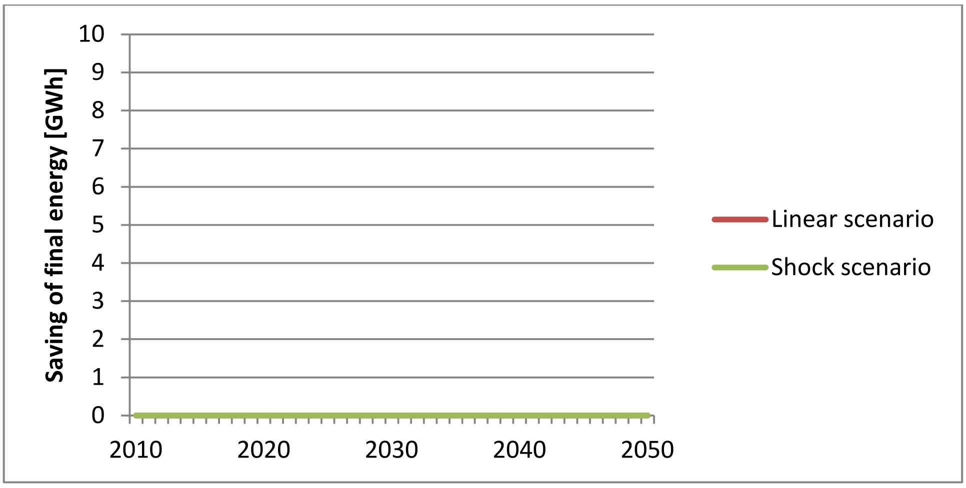

Fig. 76: Saving of final energy for producing roof tiles by using the linear and shock scenario compared of the reference scenario

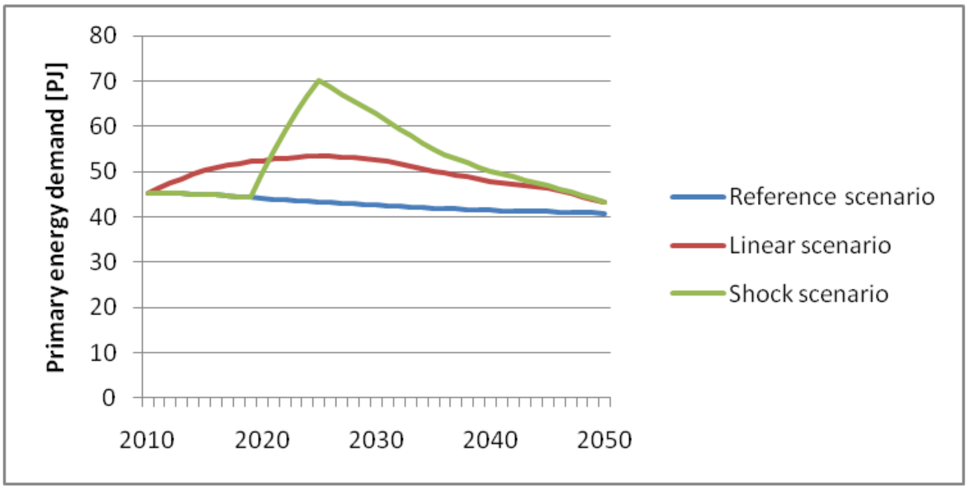

Fig. 77: Primary energy demand for producing roof tiles from 2010 to 2050

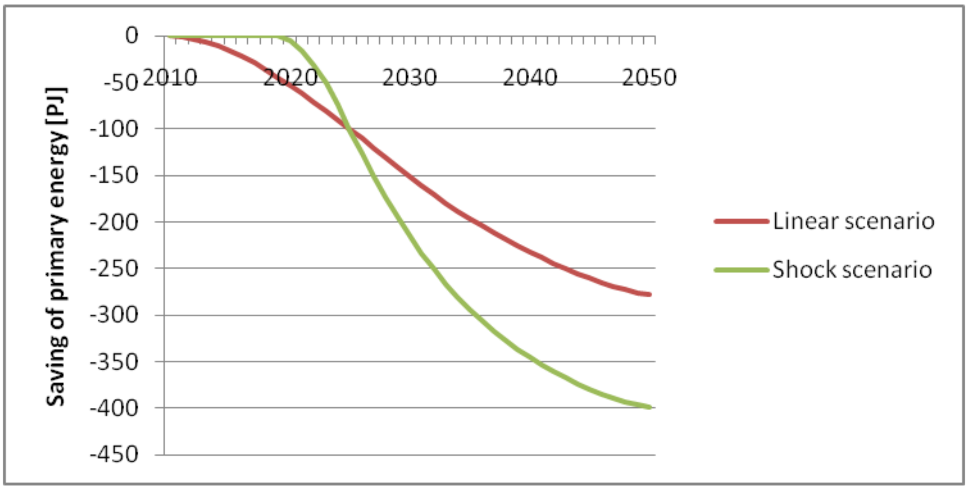

Fig. 78: Saving of primary energy for producing roof tiles by using the linear and shock scenario compared of the reference scenario

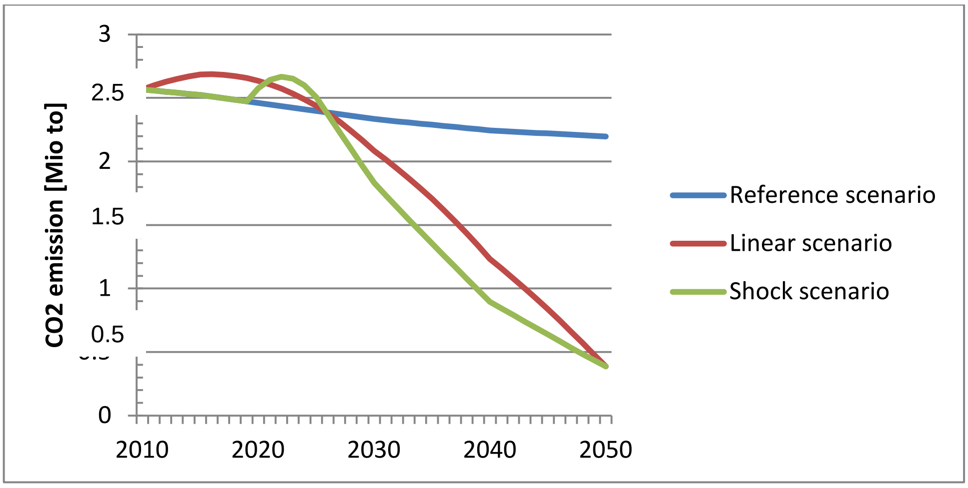

Fig. 79: CO2 emission for producing roof tiles from 2010 to 2050

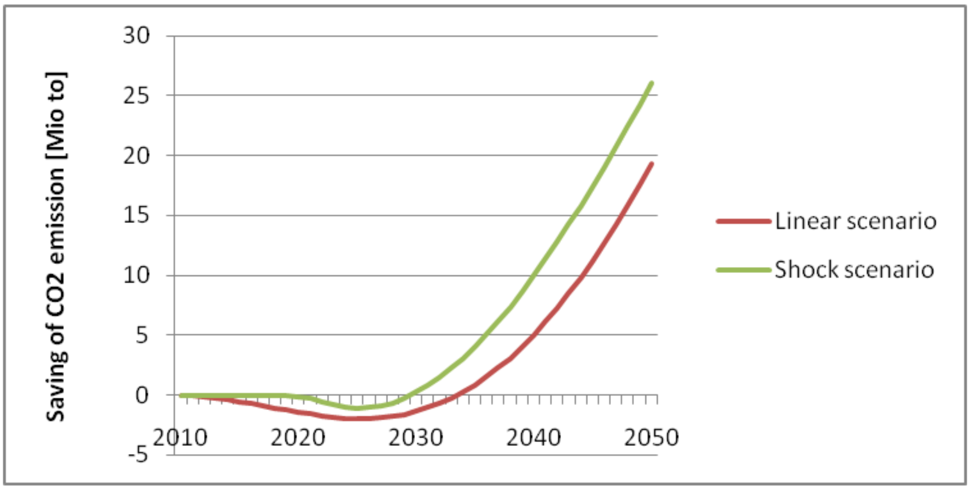

Fig. 80: Saving of final energy for producing roof tiles by using the linear and shock scenario compared of the reference scenario

4.6.4 Cement industry

In the EU-27 in 2008 the yearly production rate for cement was 255,4 million tons[20]. The specific use of energy for the cement production is about 867 kWh/to[21]. This value is an average over all different oven types for producing lime. This leads to a final energy demand of 221432 GWh. The rate of petcoke is 41,2 %, coal is 23,6 %, lignite is 4,3 %, gas is 0,9 %, fuel oil 2,7 %, waste fuels is 15,9 % and the rate of electrical energy is 11,4 %[21]. The cement industry is very energy intensive. The basic material for the cement manufacturing is gained in the stone quarry and contains limestone, clay, sand and iron ore. The process begins with the decomposition of the contained calcium carbonate ($CaCO_3$) at about 900 °C. Calcium oxide (CaO, lime) and carbon dioxide (CO_2) leave the $CaCO_3$. This process is also called calcinations. The next step is the clinkering-process. At high temperatures between 1400°C and 1500 °C the raw material reacts with silica, aluminum, ferrous oxide, aluminates and ferrites of calcium to a clinker. Afterwards these clinkers are grounded together with gypsum and other additives[21].

The use of final energy, primary energy, CO_2-emission and the integrated savings can be seen in the following figures. The production of cement has saving potentials of CO_2-emission but needs an additional use of primary energy. By taking the linear scenario instead of the reference scenario 1.6 billion tons of CO_2-emission can be saved while 7,181 PJ of primary energy has to be used additionally. By using the shock scenario instead of the reference scenario it is possible to save 2.2 billion tons of CO_2-emission while 10,311.7 PJ of primary energy are needed additionally. The demand of final energy remains constant for the whole time period and for all scenarios. Because of this no final energy can be saved.

[20] **Verein Deutscher Zementwerke e.V. (VDZ). May 2011.** *Zahlen und Daten 2010-2011.* Berlin : s.n., May 2011.

[21] **Umweltbundesamt (German Federal Environment Agency). May 2010.** *Merkblatt über die Besten Verfügbaren Techniken in der Zement-, Kalk- und Magnesiumoxidindustrie.* Dessau : s.n., May 2010.

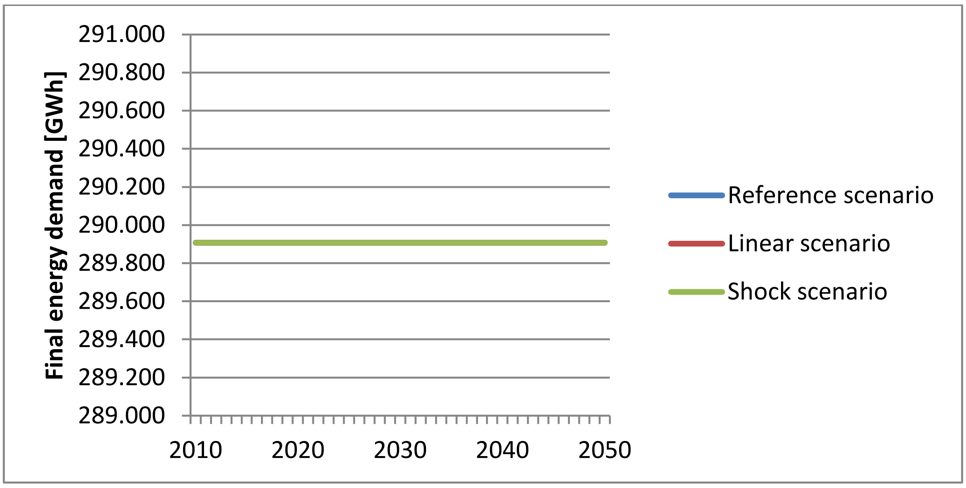

Fig. 81: Final energy demand for producing cement from 2010 to 2050

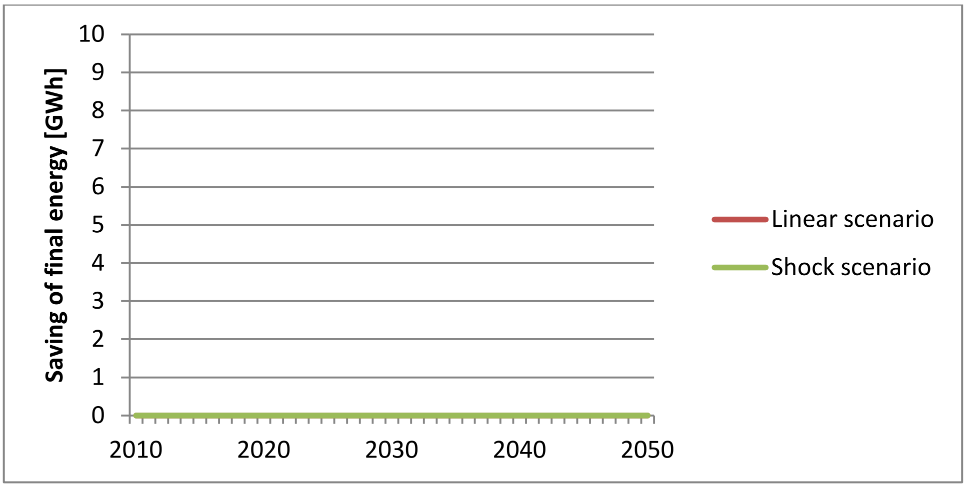

Fig. 82: Saving of final energy for producing cement by using the linear and shock scenario compared of the reference scenario

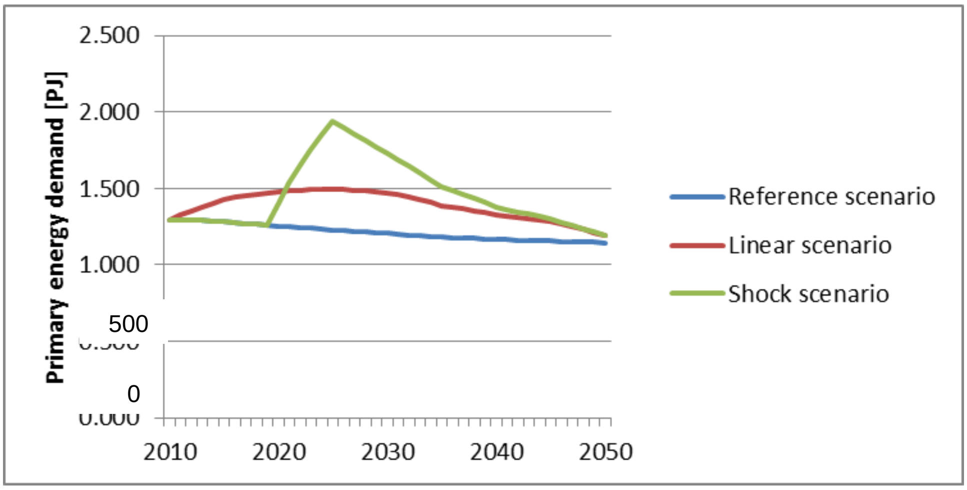

Fig. 83: Primary energy demand for producing cement from 2010 to 2050

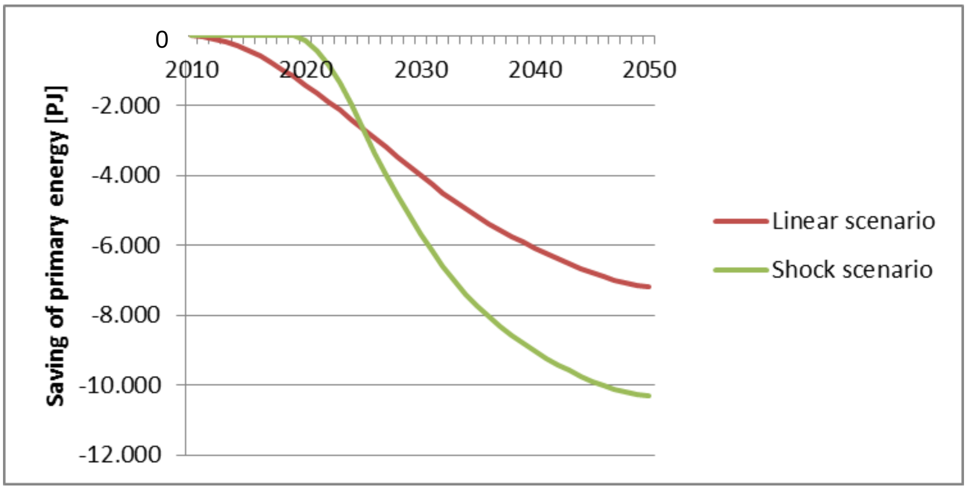

Fig. 84: Saving of primary energy for producing cement by using the linear and shock scenario compared of the reference scenario

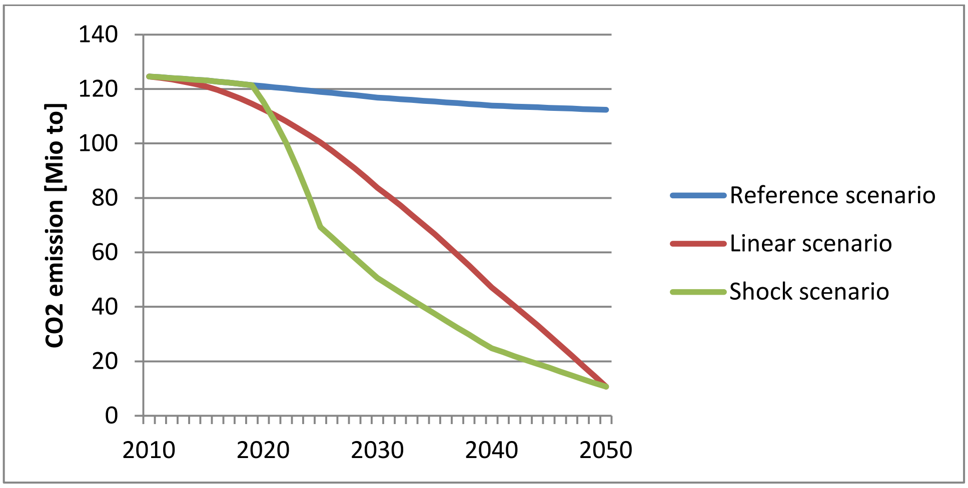

Fig. 85: CO2 emission for producing cement from 2010 to 2050

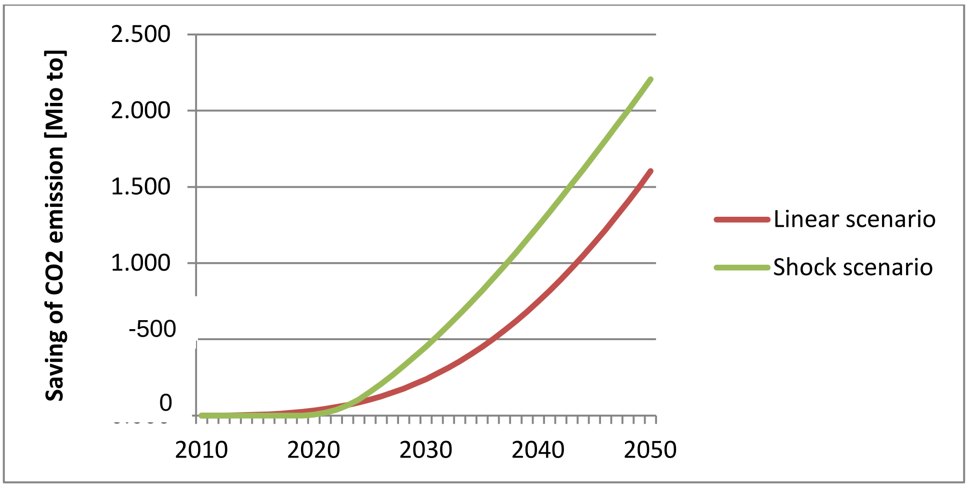

Fig. 86: Saving of final energy for producing cement by using the linear and shock scenario compared of the reference scenario

4.6.5 Lime industry

In the EU-27 in 2006 the yearly production rate for lime was 28 million tons[21]. The specific use of energy for the lime production is about 1.3 MWh/to[21]. This value is an average over all different oven types for producing lime. This leads to a final energy demand of 28,976 GWh. The rate of gas is 90 %, oil 2 % and the rate of electrical energy is 8 %[21]. The raw material for the lime production is lime stone which is gained in quarries or mines. The production is similar to the cement production. The calcium carbonate ($CaCO_3$) in the limestone is calcinated at about 900 °C. The resulting lime is called quick lime. Together with water the quick lime can be hydrated and is now called hydrated lime. The hydration is an exothermic reaction.

The use of final energy, primary energy, CO_2-emission and the integrated savings can be seen in the following figures. The production of lime is similar to the cement production in terms of saving possibilities. By using the linear scenario instead of the reference scenario 150.2 million tons of CO_2-emission can be saved while 1,047.8 PJ of primary energy has to be used additionally. By using the shock scenario instead of the reference scenario it is possible to save 205.4 million tons of CO_2-emission while 1,502.4 PJ of primary energy are needed additionally. There are no saving possibilities for final energy.

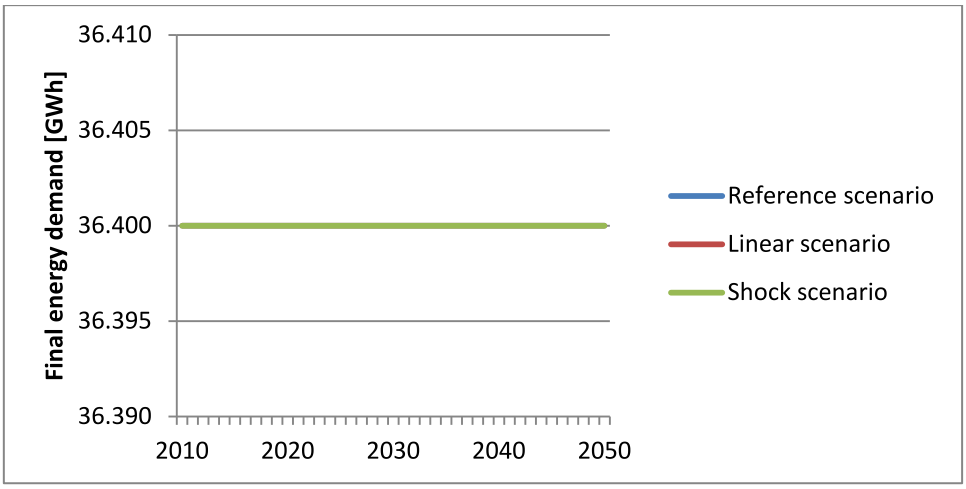

Fig. 87: Final energy demand for producing lime from 2010 to 2050

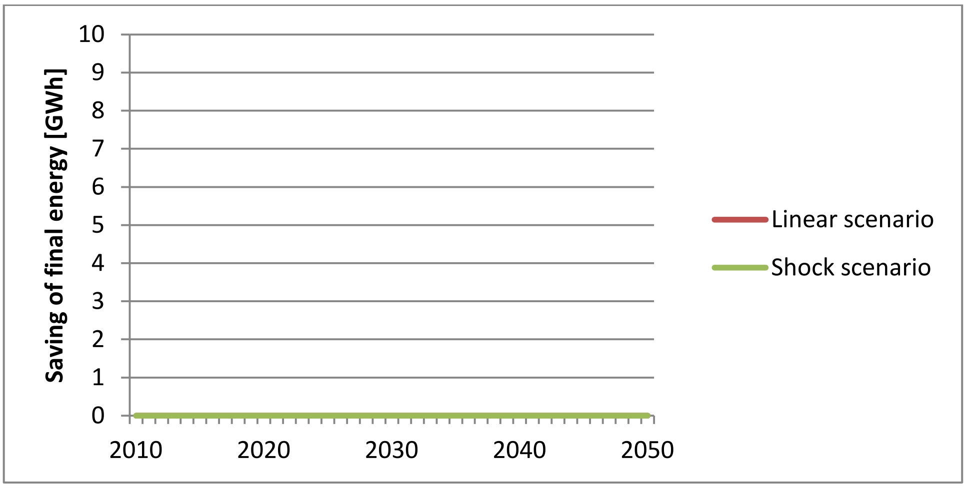

Fig. 88: Saving of final energy for producing lime by using the linear and shock scenario compared of the reference scenario

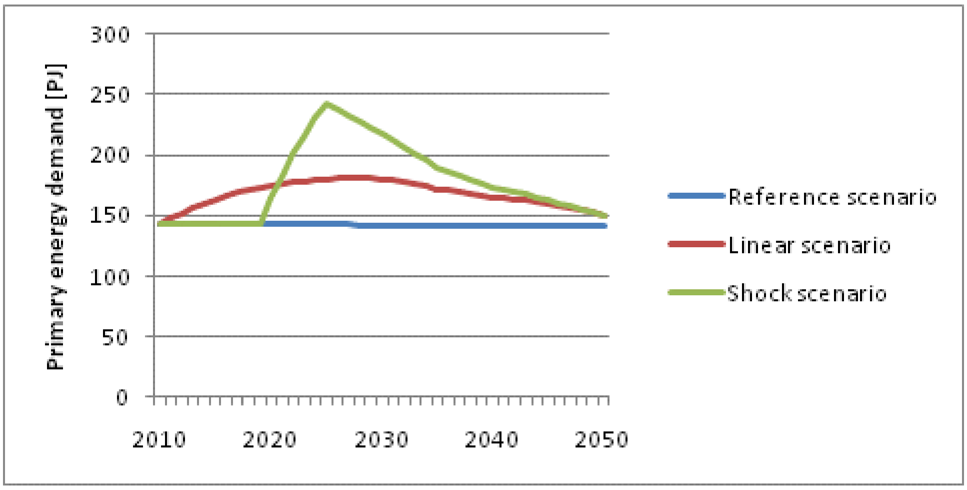

Fig. 89: energy demand for producing lime from 2010 to 2050

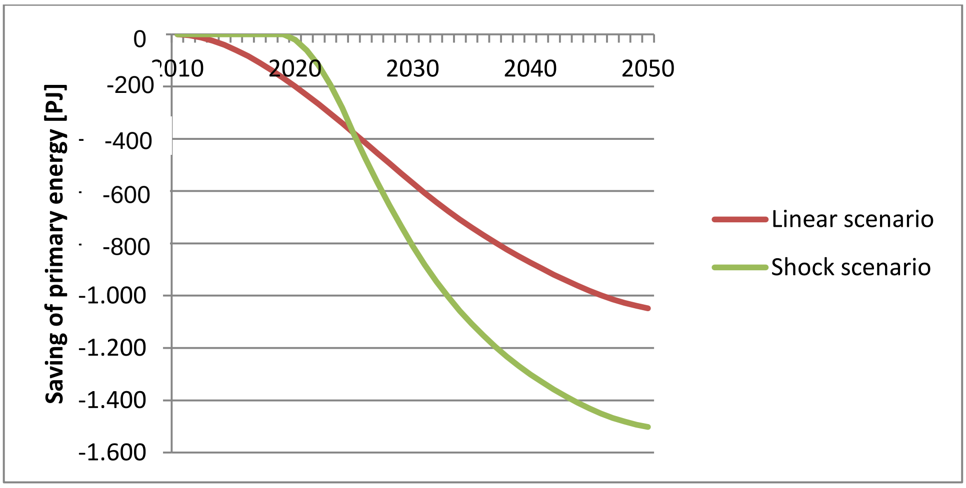

Fig. 90: Saving of primary energy for producing lime by using the linear and shock scenario compared of the reference scenario

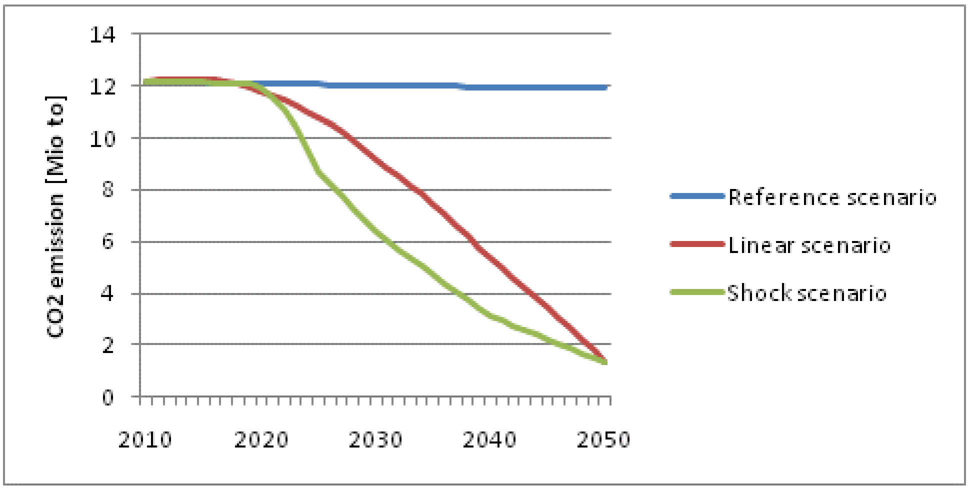

Fig. 91: CO2 emission for producing lime from 2010 to 2050

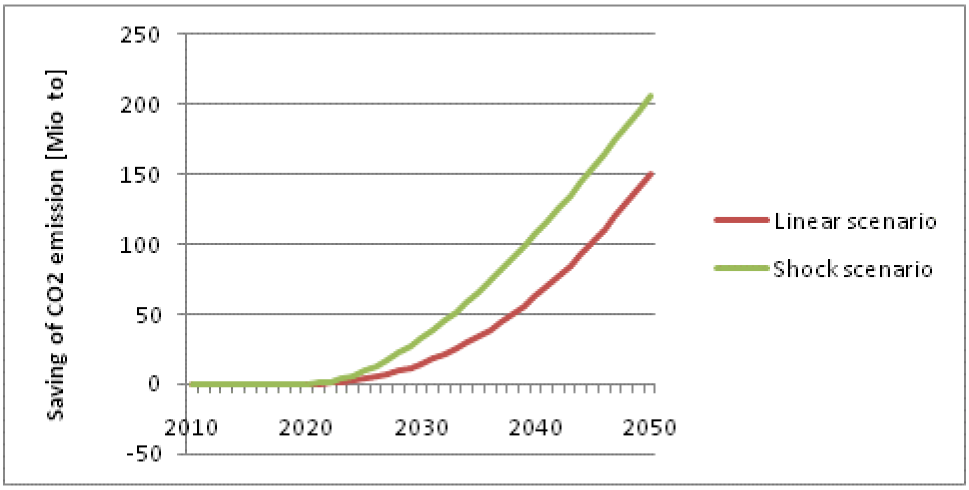

Fig. 92: Saving of final energy for producing lime by using the linear and shock scenario compared of the reference scenario

4.7 Paper and printing

In the EU-27 in 2009 the yearly production rate for paper, carton and pasteboard was 87.1 million tons[22]. The process of paper production consists in principle of four steps. It starts with the pulp production, followed by conditioning and the paper machine and it ends with the refinement. The pulp production produces single fibers for the processing. This can be done by recycling old paper or by defibering wood. For both processes mechanical and thermal energy energy is needed especially for the comminution. The conditioning process includes suspending, cleaning and grinding of the pulp, mixing of different types of fibers and the addition of fillers. In the third production step the paper is produced out on the paper machine. This step is subdivided into seven, pressing, drying and rolling up the paper web. The seven machine has the task to spread the raw material on the paper machine in an evenly way. The first amount of water is removed. In the press the paper web is drained even more. This is very important, because the more you drain the paper with the press the less you have to do it with the thermal dryer that is much more energy-intensive. In the dryer the paper is drained up to a residual moisture of approx. 5-8%. After this procedure the paper is smoothed and rolled up. The last production step is the refinement. Here the paper gets coated and satined, depending on the desired properties. The specific use of energy for the paper production was 2.7 MWh/ton in the year 2001[23]. This leads to a final energy demand of 200,300 GWh. The rate of hard coal is 12 %, oil 2 %, gas 42 % and the rate of electrical energy is 30 %[23].

The use of final energy, primary energy, CO_2-emission and the integrated savings can be seen in the following figures. The production of paper has saving potentials of CO_2-emission but needs an additional use of primary energy. By taking the linear scenario instead of the reference scenario 374.4 million tons of CO_2-emission can be saved while 3,814.7 PJ of primary energy has to be used additionally. By using the shock scenario instead of the reference scenario it is possible to save 508.1 million

[22] **Verband Deutscher Papierfabriken e. V. (VDP). 2011.** Papier Kompass 2011. Bonn : VDP, 2011.

[23] **Bayerisches Landeramt für Umweltschutz (LfU). 2002.** Klimaschutz durch effiziente Energieverwendung in der Papierindustrie. *Nutzung von Niedertemperaturabwärme.* Augsburg : LfU, 2002.

tons of CO_2-emission while 5,469.7 PJ of primary energy are needed additionally. The demand of final energy remains constant for the whole time period and for all scenarios. Because of this no final energy can be saved.

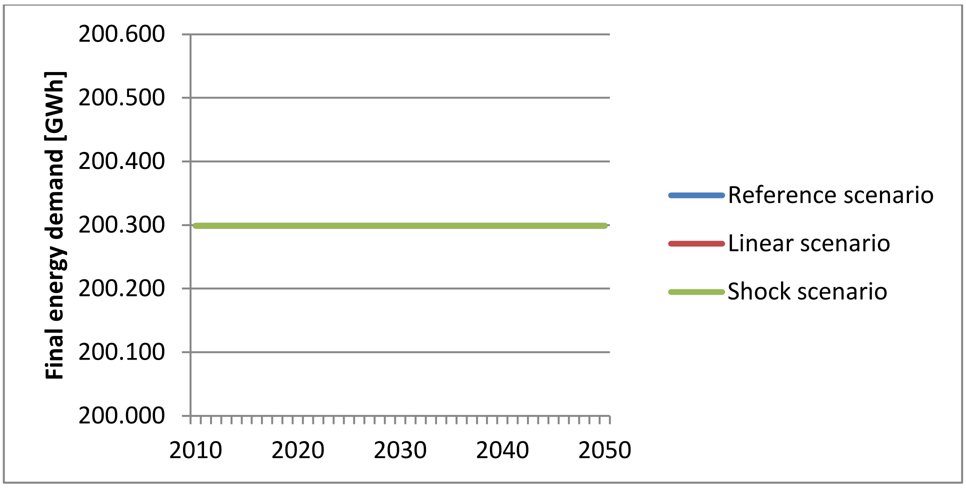

Fig. 93: Final energy demand for producing paper from 2010 to 2050

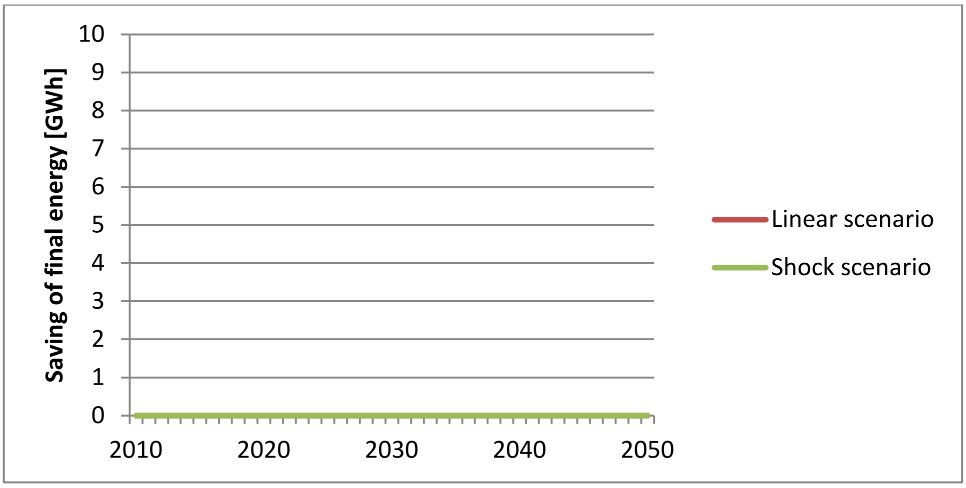

Fig. 94: Saving of final energy for producing paper by using the linear and shock scenario compared of the reference scenario

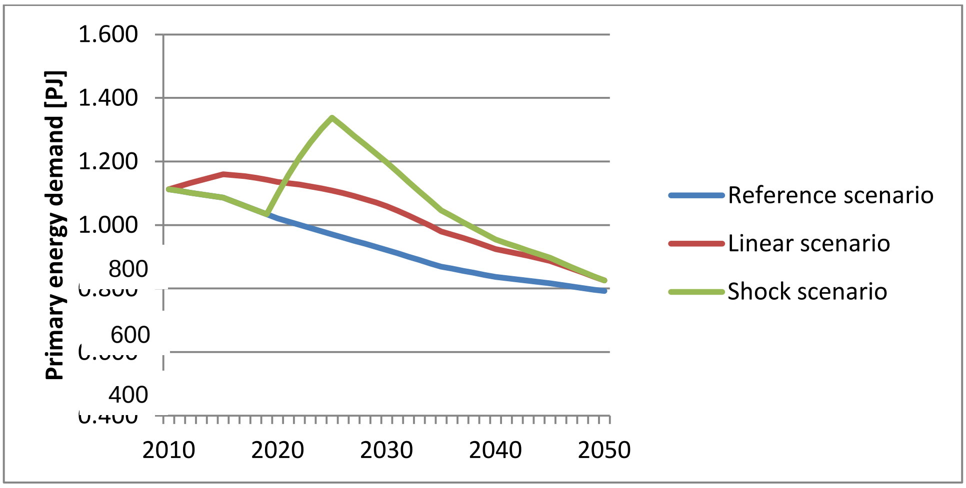

Fig. 95: Primary energy demand for producing paper from 2010 to 2050

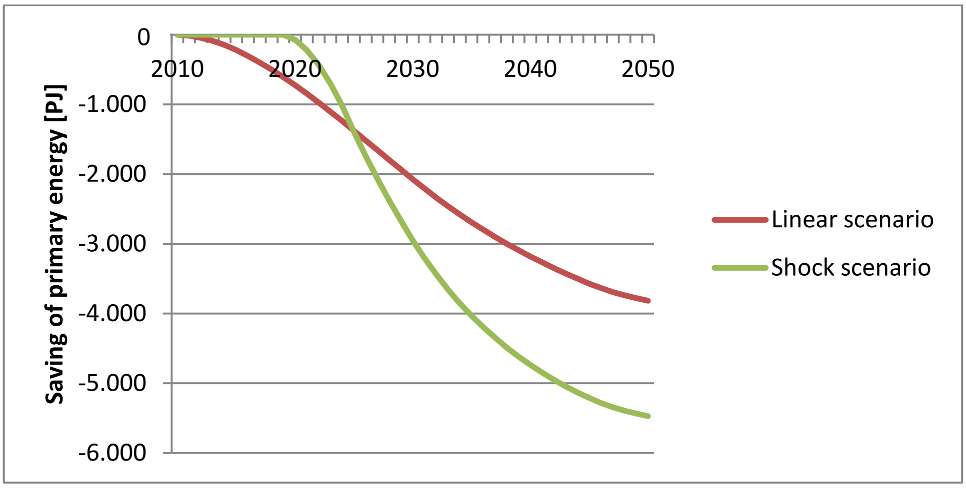

Fig. 96: Saving of primary energy for producing paper by using the linear and shock scenario compared of the reference scenario

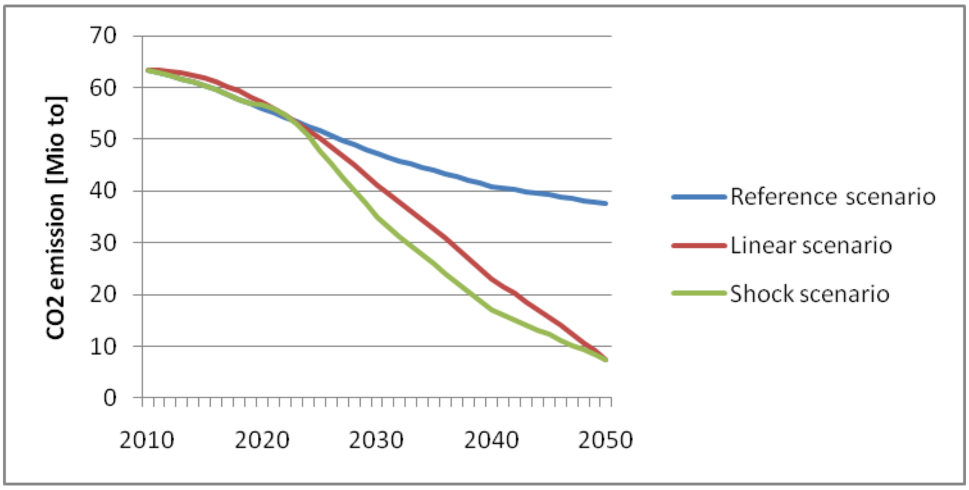

Fig. 97: CO2 emission for producing paper from 2010 to 2050

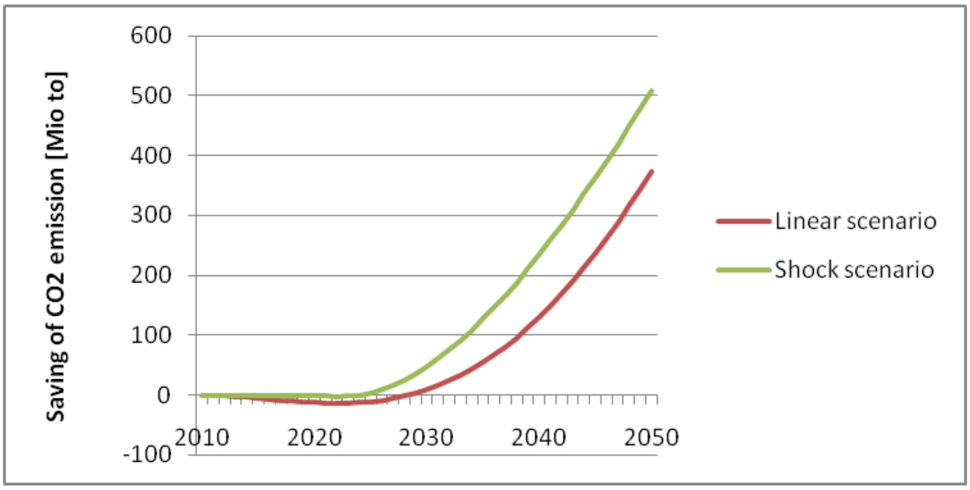

Fig. 98: Saving of final energy for producing paper by using the linear and shock scenario compared of the reference scenario

5. Conclusion

The work in hand makes clear that a switching of fuel operated industrial processes to electro-thermal processes offers big potentials for saving of primary energy and CO_2-emission. Altogether five energy intensive industrial branches have been analysed with the help of case studies. These five industry sectors ordered by the final energy demand in 2009 are the chemical industry with 585,896 GWh, the iron and steel industry with 514,848.47 GWh, the glass, pottery and building material industry with 424,832.27 GWh, the paper and printing industry with 384,115.64 GWh and the non-ferrous metal industry with 103,681.45 GWh.

In the year 2010 the calculated final energy demand for the plastic production was 110,500 GWh. This covers about 18.8 % of the chemical industry. The calculated final energy demand for the steel production was 434,923 GWh and 10,972 GWh for the production of grey iron. Consequently the sum of 445,904 GWh covers about 86.6 % of the full iron and steel industry. The final energy demand for the glass production is 55,500 GWh, for the roof tile production 10,493 GWh, 28,976 GWh for the brick production, 289,907 GWh for the cement production and 36,400 GWh for the lime production. The sum of 421,275 GWh covers about 99 % of the glass, pottery and building material industry. The final energy for producing paper was calculated with 200,299 GWh that covers 52 % of the overall paper and printing industry. The production of casted aluminum needs about 2,774 GWh of energy that covers 2.7 % of the complete non-ferrous metal industry.

Table 3 summarizes the share of the calculated final energy demand on the overall final energy demand of the five different branches. The table gives an overview how much the case studies cover the overall energy demand. Table 4 summarizes the yearly savings respectively the additional yearly amounts of final energy, primary energy and CO_2-emission that can be achieved after the year 2050. This year marks the point when a complete switching to EPM technologies is realized. As shown in the table 4 all together 67,512.66 GWh of final energy can be saved yearly in the ten regarded industry sectors. This means a decrease of 13.7 %. In terms of primary energy the saving per year after 2050 is 210.29 PJ which connotes to a decrease of 4.1 %. The most substantial saving can be achieved with CO_2-emission. 246.56 million tons of CO_2-emission can be saved yearly which is related to a decrease of 63.4 %.

It is remarkable that the consumption of primary energy increases for all industry sectors except the Iron & Steel industry and the NF metals industry. The reason for this additional effort of primary energy can be explained with the particular primary energy factor. The PEF for electrical power is higher than the PEF´s for other energy carriers like coke, natural gas, lignite and petroleum products. This is status of today and it will still be the case in the year 2050. The steel and NF-metal industry will achieve a decrease in the primary energy consumption in spite of that. The reason is that here the process is completely changed in particular the physical heating principle. In the grey iron industry for example a switching from a coke fired cupola furnace to an induction furnace is realized. The induction furnace has a high efficiency and needs much less final energy than the cupola furnace which leads to savings of final energy as well as primary energy consequently. In the other branches (Chemical, Glass, pottery & building materials and Paper & printing) the complete process, in particular the physical principal of the heating process, is not changed but only the energy carrier. This has no significant effect on the demand of final energy.

Table 5 summarizes the integrated savings respectively additional amounts of final energy, primary energy and CO_2-emission that can be achieved in the time period from 2010 to 2050. It is obvious that the savings depend on the chosen scenario.

Branch	Industry sector	Calculated final energy demand in 2010	Final energy demand of the branch	Share
Chemical	Plastic	110,500		
Sum		110,500	585,896	19 %
Iron & steel	Steel	434,923		
	Grey iron	10,972		
Sum		445,904	514,848	87 %
Glass, pottery & building materials	Glass	55,500		
	Roof tile	10,493		
	Brick	28,976		
	Cement	289,907		
	Lime	36,400		
Sum		421,275	424,832	99 %
Paper & printing	Paper	200,299		
Sum		200,299	384,116	52 %
NF metals	Aluminum	2,774		
Sum		2,774	103,681	3 %

Table 3: Share of the calculated final energy demands on the overall energy demand of the five different branches.

Branch	Industry sector	Final energy		Primary energy		CO_2-emission	
		GWh	%	PJ	%	Million tons	%
Chemical	Plastic	0	0	-10.35*	-2.3	8.93	68.7
Iron & steel	Steel	63,319.02	13.2	315.71	14.1	74.70	39.5
	Grey iron	2626.00	23.9	10.21	23.0	2.63	77.1
Glass, pottery & building materials	Glass	0	0	-9.43	-4.3	10.33	83.4
	Roof tile	0	0	-2.45	-6.0	1.81	82.3
	Brick	0	0	-6.85	-6.1	5.11	82.7
	Cement	0	0	-49.80	-4.3	101.61	90.5
	Lime	0	0	-9.25	-6.6	10.59	88.8
Paper & printing	Paper	0	0	-33.49	-4.2	30.14	80.3
Non-ferrous metals	Aluminum	1567.64	56.5	5.99	54.,9	0,71	77.2
Sum		67,512.66	13.7	210.29	4.1	246.56	63.4

Table 4: Savings of final energy, primary energy and CO_2-emission per year after 2050 (* Negative numbers imply an additional effort).

Branch	Industry sector	Saving potentials for using the linear scenario			Saving potentials for using the shock scenario		
		Final energy	Primary energy	CO_2-emission	Final energy	Primary energy	CO_2-emission
		GWh	PJ	Million tons	GWh	PJ	Million tons
Chemical	Plastic	0	-1,245.8*	102.6	0	-1,786.9	138.5
Iron & steel	Steel	1,298,039.8	5,678.5	1,469.6	1,804,591.2	7,852.2	2,039.9
	Grey iron	53,833	135.6	48.1	74,841	184.5	66.6
Glass, pottery & building materials	Glass	0	-1,258.3	128.9	0	-1,806.0	175.0
	Roof tile	0	-278.0	19.4	0	-398.7	26.0
	Brick	0	-779.8	55.0	0	-1,118.1	73.9
	Cement	0	-7,181.5	1,603.5	0	-10,311.7	2,204.6
	Lime	0	-1,047.8	150.2	0	-1,502.4	205.4
Paper & printing	Paper	0	-3,814.7	374.4	0	-5,469.7	508.1
Non-ferrous metals	Aluminum	32,136.7	104.9	13.3	44,677.9	144.8	18.3
Sum		1,384,009.5	-9,686.9	3,965.0	1,924,110.8	-14,212	5,456.3

Table 5: Savings of final energy, primary energy and CO_2-emission for the two the different industry sectors for both switching scenarios (* Negative numbers imply an additional effort).

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