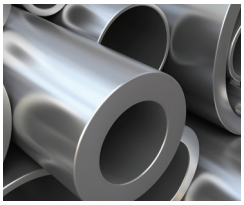


Technical report

EuLA

A COMPETITIVE AND EFFICIENT LIME INDUSTRY

Cornerstone for a Sustainable Europe

A Competitive and Efficient Lime Industry
Cornerstone for a Sustainable Europe

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Final Report

Executive Summary

Increasing carbon constraints towards 2050 invite the European lime industry to look for ways to become even more CO_2-efficient, while maintaining its global competitiveness.

This Roadmap 2050 regards improved energy efficiency and fuel switch (from fossil solid fuels to gas or biomass), and concludes that these options have limited impact. Two-third of all carbon emissions in lime production are released from the raw material during the production process and can be reduced by Carbon Capture and Storage or Utilization, for which the business case needs to improve to become attractive.

In a Europe with increasing pressure on CO_2 emission, the competitiveness of the lime industry needs special attention, particularly in the framework of the EU emissions trading scheme. Unilateral EU pressure on CO_2 emissions from the manufacturing industry could reduce both the EU demand for lime (in case of carbon leakage in customer sectors) and the share of the remaining EU demand that is produced in the EU.

The lime industry, through its multiple applications and its essential role for downstream industries, sits at the beginning of the value chain in Europe. Used in many products of the everyday life, lime is probably the most versatile natural chemical for a wide range of processes. The absorption and neutralization capacities of lime are playing an important role in environmental protection, for the treatment of flue gases and for the purification of water. Traditionally used in the agriculture, lime provides better efficiency for fertilizers and participates in animal feed and hygiene. As a key element for soil treatment, lime is used to treat polluted soils and waste water. Lime is also an essential enabler for many manufacturing industries. It helps producing high strength steel for lighter cars, high performing construction materials for sustainable housing, and provides a longer life cycle to civil engineering applications, such as asphalts. The vast majority of the lime consumed in Europe is currently also produced in Europe.

Lime production is carbon intensive. CO_2 is released in the production process, originating from the raw materials. Also, the energy generation that is necessary for the process, generates CO_2 emissions. This Roadmap shows the options to reduce the energy use and carbon intensity. The result is summarized in Figure 1.

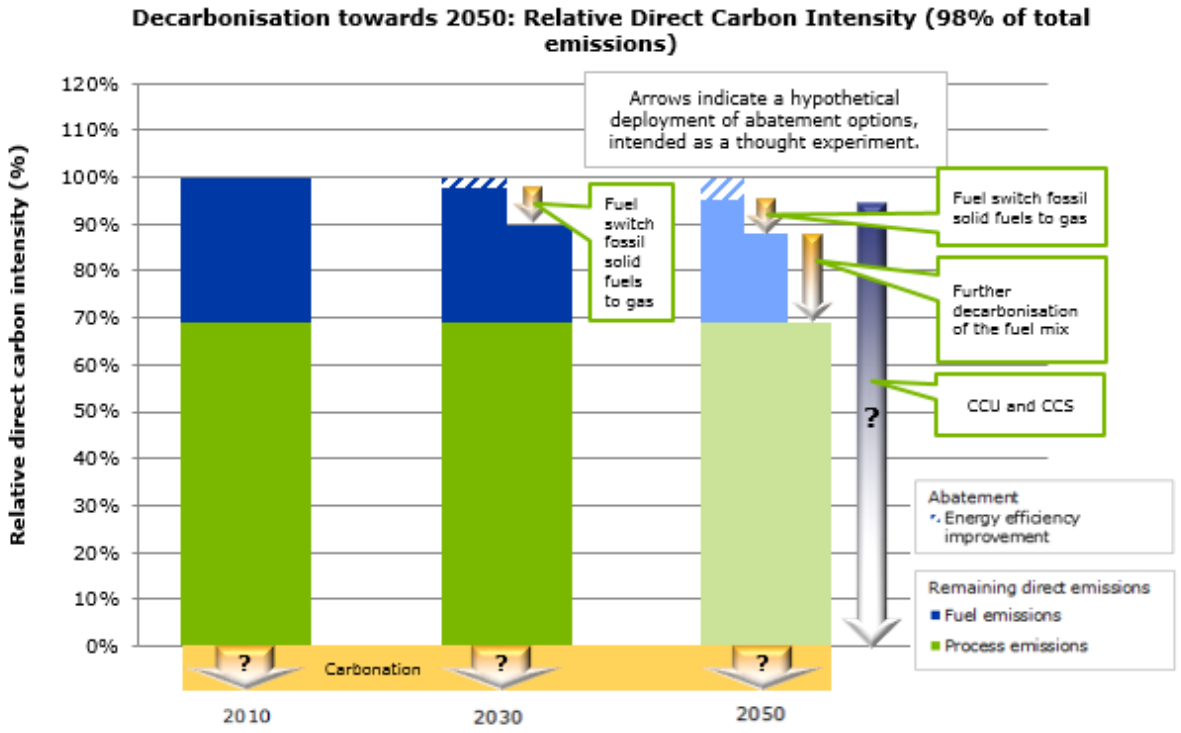

Figure 1: Possible development of the carbon intensities of lime production for 2030 and 2050, compared to 2010. Direct emissions only, which form about 98% of total emissions. The scope of these emissions is from factory gate to factory gate. Green bars reflect process emissions, blue bars reflect fuel emissions and the striped blue block indicates energy efficiency abatement. The orange bar reflects the – unknown – effect of natural carbonation. The arrows (apart from the arrows in the carbonation part) indicate the technical potential of emission reduction options[1]. Note that intensities do not include upstream emissions related to fuel production (mainly relevant for bio fuel; refer to paragraph 5.2.2.1).

Reduction potential for energy related emissions

For one-third of all emissions that originate from energy production, the lime industry can apply 'usual' abatement measures like fuel switch and energy efficiency.

One option to reduce emissions from energy production is the **switch to fuels with reduced carbon intensity**, such as natural gas or biomass. Switching to gas may have a positive impact on the quality of the produced lime, but is in many cases more expensive than solid fossil fuels-based production. Switching to biomass requires additional investments, especially when switching from natural gas. As is shown in Figure 1 the impact of complete fuel switches to gas or biomass only applies to the energy generation related emissions, not to the process emissions.

[1] The effectiveness of CCS to reduce the CO_2 intensity could in practice be limited by unavoided CO_2 emissions resulting from the generation of power and heat, and by the incomplete capture rate of CO_2. This is one of the reasons for representing the arrow more vaguely in the downward direction, and for the question mark in the arrow.

Improving the energy efficiency is another important option to reduce energy related emissions. Vertical lime kilns, such as the Parallel Flow Regenerative Kiln, are already highly efficient, and perform close to their thermodynamic minimum energy use. The biggest potential lies in replacing horizontal kilns—which are less energy efficient—by vertical ones. This replacement can be challenging, as each kiln type has its specific applicability (different feeds (particle size), different products, and different optimal operation conditions). In case all investments have to be earned back by saved energy purchase costs, the abatement costs are mostly ≥ €38/tonne.

Furthermore, measures such as improving the internal use of heat and exporting residual heat have some potential. The economical attractiveness of such measures has to be considered individually. As is shown in Figure 1, the impact of energy efficiency improvements is limited.

The biggest part of CO_2 emissions in lime production—about two-third—originate from the raw materials. **The biggest potential reduction of the carbon intensity could come from Carbon Capture and Storage (CCS) and/or Carbon Capture and Utilization (CCU)**. While the cost to capture carbon is already high, costs for transport to a suitable storage location and for storage of CO_2 add to these costs. Even optimistic perspectives on CCS cost reduction will considerably increase the total production costs for lime. Giving the captured CO_2 a value (CCU) could improve the business case. For now, CCS in the lime industry is not a viable option and will not take off without an external incentive. In case CCS/CCU would be well incentivized in a manner safeguarding the EU lime industries competitive position, the right technological development and infrastructural requirements, the EU lime industry would embrace CCS/CCU. Currently, it is already contributing to research inwards the (technological) development of CCS.

The last factor in Figure 1, natural carbonation (lime capturing CO_2 from the atmosphere), could reduce part of the total impact of the production and use of lime products. The EU lime industry is looking forward to map this positive effect in more detail and discuss with stakeholders in what manner this can be taken into account in LCA's and policy making.

Carbon Cost and Competitiveness

The EU lime industry sits at the start of value chains, supplying to various other industrial sectors. Unilateral European carbon costs would therefore have two impacts:

- The EU industrial client sectors could relocate their production, reducing EU demand for lime products. To prevent this, the EU lime industry needs a stable EU industry base to prosper;
- The share of the EU demand for lime that is produced in the EU could decrease:
    - Because of the high carbon intensity of the lime production processes, pricing carbon directly causes higher costs for lime production. E.g., an increase in carbon prices equivalent to €1/tonne CO_2 translates into a lime production average cost increase by €1,1/tonne quicklime (for comparison: EU production costs vary between €55 and €70/tonne).
    - This high sensitivity for energy and carbon prices has a large impact on competitiveness. Combined cost of an EU unilateral carbon price of €5/tonne CO_2 on top of the existing disadvantages in energy prices, could exceed transport costs for import for some European kilns. When carbon costs increase even more, it pays off to import lime from even larger distances.

When the EU manufacturing industries – including the EU lime industry – are competitive, the EU lime industry will be able to invest – a precondition for the abatement measures described above.

Policy recommendations

For the European Lime Industry, important considerations for the future energy and climate policy framework are:

- Long-term policy certainty allows EU industries to prepare and make investment decisions on emission reduction;
- A global level playing field for carbon costs for lime manufacturers prevents carbon leakage;
- If such a global level playing field lacks, a cost levelling mechanism for climate costs is needed for the EU lime industry to maintain competitiveness;
- In the assessment of competitiveness, differences in energy prices should be taken into account as well;
- European energy policy should:
    - Include fully integrated and well-functioning electricity and natural gas markets;
    - Consider to integrate energy requirements in international negotiations;
    - Guarantee a diverse and more competitive energy supply in Europe;
    - Eliminate differences of energy prices within Europe as a consequence of national differences in energy taxation;
- As the most important abatement option for the lime industry, CCS/CCU needs to be developed and deployed; this includes solving liability issues. The European Commission may consider investigating the possibility of providing public infrastructure for transporting and storing CO_2. This enables EU lime industry to quickly take CCS/CCU on board once economically viable;
- Future targets should not take the feasibility of large scale implementation of CCS/CCU for granted, take differences between sectors into account, and provide long term certainty.
- The European Commission could stimulate these innovations by stimulating research while taking intellectual property rights into account, reducing barriers for subsidies, and by developing adequate financing systems for the early adoption of energy efficient and low carbon techniques.
- The industry needs access to innovative investment models to attract finance for measures that do not meet the industry financial thresholds, or other forms of support for low-carbon investments. These systems could be financed by using part of the revenues from ETS to provide cheaper loans for low carbon investments in installations falling under the EU ETS.
- Consider to recognise the potential of lime products to react with CO_2 and further reduce the level of CO_2 in the atmosphere (carbonation). EuLA will continue to work to provide more insight.

Table of contents

1 Introduction

This chapter provides a brief introduction of the EU lime industry and the European Lime Association (EuLA). It also describes the purpose of this Roadmap and information on how it was prepared. At the end of the chapter, a reading guide provides more information on the contents and structure of this report.

1.1 Who we are

The raw material calcium carbonate is widespread through nature; the Earth's crust contains more than 4% of calcium carbonate (EuLA, 2013). However, it is rare to find deposits which contain sufficient amounts of resources with high chemical purity and the right physical and mechanical properties (JRC, 2013 (BREF)).

Currently, lime is used in a wide range of applications. Lime is made by heating calcium carbonate ($CaCO_3$), leading to the release of CO_2 and the production of lime (calcium oxide; CaO). Production of lime leads therefore – and as a consequence of the heat requirements – to emissions of greenhouse gases. In 2012, the total CO_2 emissions of the European lime industry were around 0.6% of the total European greenhouse gas emissions (refer to paragraph 5.1.2 and (EEA, 2013)).

Text Box 1: The European Lime Association

The European Lime Association (EuLA) gathers the non-captive lime producers organised in national associations that put lime as a product in the market. It represents:

- About 95% of the European non-captive lime production;
- 21 national organisations;
- Approximately 50 companies;
- 190 production sites;
- 470 lime kilns;
- 11.000 direct employees;
- 22 million tonnes total lime and dolime production for 2011;
- Around €2.5 billion contribution to Europe's GDP.

As the voice of the European lime sector, its activities and mission focus on:

- Promoting the interests of the European lime industry on all non-commercial issues of common concern, such as sustainable development, product legislation, energy, environmental protection, health and safety, communication and image enhancement.
- Providing the members with a single voice and competent assistance to address the complex legislative framework on scientifically and technically-sound dossiers.
- Ensuring that the lime industry at large benefits from the sharing of non-sensitive information and playing a supporting role in the promotion of best practices.

1.2 Aim of this Roadmap

The EU Member States agreed to three targets for 2020 related to energy and climate change, being:

- A 20% reduction in GHG emissions in 2020 compared to 1990 levels;
- A 20% share of renewable energy in the EU energy mix in 2020;
- 20% energy savings in 2020 compared to projected business as usual levels.

At the same time, Europe wants to strengthen its manufacturing base through raising its contribution to the EU's gross domestic product (GDP) to 20% by 2020 (European Commission, 2012).

In order to keep the global temperature rise below 2°C, the European Council has agreed on the long term EU objective of reducing GHG emissions by 80-95% by 2050 compared to 1990. Possible routes to reach such a low carbon economy in 2050 and the policy options beyond 2020 are being explored by the European Commission.

In 2011, the European Commission published a roadmap for moving to a competitive low carbon economy ("Low Carbon Economy Roadmap") (European Commission, 2011a). This roadmap sets out the main elements shaping the EU's climate action to enable Europe to become a competitive low carbon economy by 2050. For industry, the analyses show that GHG emissions could be reduced by 83% to 87% in 2050, while it is acknowledged that continued measures to support the competitiveness of energy intensive and trade exposed industry are required in the absence of global action[2]. It also emphasises that for industry the solutions are sector-specific and the European Commission clearly sees the need to develop specific roadmaps in cooperation with the sectors concerned.

Furthermore, the European Commission published the EU Energy Roadmap (European Commission, 2011b), to investigate possible scenarios to decarbonise the energy system. This roadmap focuses on decarbonisation scenarios. Energy related GHG emissions reduction for industry in each of the decarbonisation scenarios is approximately 80% in 2050 as compared to 1990 levels.

The European lime industry sees these developments as an opportunity to assess the possibilities for its industry. This Roadmap thereby forms important input in the 2030 framework for Climate and Energy Policies.

1.3 Preparation of this Roadmap

This is the EU Lime Industry Roadmap. EuLA coordinated the activities leading to the preparation of this Roadmap starting with an intensive phase of collecting evidence as input for the Roadmap. Then, EuLA assigned Ecofys to:

- First, facilitate a workshop with the sector, in which the storyline for this Roadmap was developed, based on sector input;
- Secondly, support them in structuring the evidence base that EuLA provided and in drafting the final text based on this input.

[2] The Low Carbon Economy Roadmap explores two options at a high-level: a lower reduction effort for the energy intensive industry, and continued support to compensate for additional costs incurred to the industry.

This Roadmap summarizes important characteristics for the EU lime industry. The outlook for 2050 should not be seen as a prediction; it is rather a projection of what the future could look like. For many parameters, the effects of hypotheses have been shown; this Roadmap is not the result of a bottom up analysis. However, the results give a clear idea of what reductions are or could become feasible in the lime sector.

The scope of this Roadmap includes:

- Non-captive lime; that is lime that is sold on the market[3];
- Energy consumption and greenhouse gas emissions;
- Scope 1 (direct emissions at the site of the lime plants) and Scope 2 (indirect emissions related to the generation of purchased electricity);
- Quicklime, dolime and sintered dolime[4].

Although lime is an important and enabling material for many sectors that allows reaching functionalities at reduced carbon footprint (hydrated lime in asphalt, aerated concrete …) this Roadmap mainly focuses on what the lime sector can influence itself.

Relation to resource efficiency

As lime is produced out of the mineral limestone, the resource efficiency aspect (optimisation of the use of resources) is playing a major role. Within the framework of the Europe 2020 Strategy, which sets five ambitious objectives on employment, innovation, education, social inclusion and climate/energy, Europe strives for smart, sustainable and inclusive growth. In January 2011, the Flagship Initiative for a Resource-efficient Europe was issued under this strategy. This umbrella communication sets out a long-term framework that promotes the shift towards a resource-efficient, low-carbon economy to achieve sustainable growth.

Although the current Roadmap is focused on low carbon and energy, the resource efficiency part is not omitted. EuLA is member of IMA-Europe, the industrial minerals umbrella association[5]. IMA-Europe has taken the initiative to develop a Resource Efficiency roadmap for the Industrial Minerals industry to document its future activities and address the challenges set by the EU.

This document is an evolving document which will be updated when necessary. Due to the difference in the time line of the elaboration of the Resource Efficiency Roadmap, its findings will be incorporated within this document at a later stage.

[3] "Captive lime" (lime that is not sold on the market, but produced for own use by companies) is not within the scope of this document.

[4] Part of the analysis is based on quicklime only, with the assumption that the starting points for quicklime apply to (sintered) dolime as well. The energy consumption to produce slaked variants (additional hydration process step) hardly differs, so these products are implicitly included as well.

[5] IMA Europe brings together a number of European associations specific to individual minerals – Andalusite, Calcium carbonates, Borates, Bentonite, Lime, Feldspar, industrial Silicas, Talc, Diatomite, Kaolin, Mica, Plastic Clays, Vermiculite and Sepiolite. Altogether, the 500 member companies operate 685 mines and quarries and 750 plants, employ around 42,000 people in 28 European countries i.e. 24 EU Member States + Norway, Switzerland, Turkey and Ukraine and produce an annual volume of some 80 million tons, contributing an annual value of around 10 billion Euros to Europe's gross domestic product.

1.4 Reading guide

This reading guide gives an overview of the content and structure of this report.

- Chapter 2 explains the markets and applications of lime products, including the sectors in which they are applied and the specific functions that they fulfil, and gives examples of the sectors' innovations.
- Chapter 3 describes the lime production process, from resource extraction to end product.
- Chapter 4 goes into detail on the position of the EU lime industry, including a section on EU production and costs, outside EU production and the trade vulnerability of the EU lime production industry.
- Chapter 5 is a large chapter which contains details on the energy use and emissions associated with lime production and the different abatement options and end of pipe solutions which can influence the carbon intensity of lime production in the EU.
- Chapter 6 contains the key findings of the report.
- Chapter 7 concludes with policy requirements for the EU lime sector based on the findings from this study.

2 Market and Applications

This chapter describes different lime products and their applications. It also provides an overview of the lime market, describing the sectors in which lime products are used and providing insight in developments of the lime market.

2.1 Lime products

The term lime is commonly used to refer to all types of lime products such as quicklime and slaked lime. There are many qualities of lime products[6], depending on:

- The presence of magnesium in the raw material, and thus in the product;
- The execution of a hydration step (called 'slaking');
- The temperature in the kiln.

Characteristics of various forms of lime are summarized in Table 1.

Table 1: Lime Nomenclatures (based on: JRC, 2013 (BREF)).

Name:	Formula[7]:	Mg:	Hydrated:	Kiln Temp (°C):	Synonyms:
Quicklime	CaO	X[8]	X	900-1200	Lime Burned lime
Dolime	CaO MgO	√	X	900-1200	Dolomitic lime
Sintered dolime	CaO MgO	√	X	Up to 1800	Dead burned dolime
Slaked lime	$Ca(OH)_2$	X[9]	√	N.A. (made from quicklime)	Calcium hydrate Calcium hydroxide Caustic lime Hydrated lime
Hydrated dolime	$CaMg(OH)_4$	√	√	N.A. (made from dolime)	Calcium magnesium hydroxide

Quicklime is - by far - the most widely produced lime product. Throughout the rest of this report, the term lime products will be used to refer to all products mentioned above.

[6] Yet another form of lime exists: Hydraulic lime. This form of lime is outside the scope of this Roadmap.
[7] While the formula suggests a mixed oxide 1:1, the actual ratio between Ca and Mg may vary.
[8] The free MgO content of quicklime is usually close to 0.9%.
[9] The free MgO content of slaked quicklime is usually close to 0.9%.

2.2 Markets of lime

Lime products are used in a wide variety of applications in Europe. Although lime products are rarely directly sold to consumers, the average EU citizen indirectly consumes around 150 g/day of lime products (EuLA, 2013b). Lime products[10] are used for many purposes, including cleaning wastewater, preparing drinking water, removing acid gases from flue gases and enhancing soil stability. Lime products are important in the steel industry and for the production of construction materials, paints, paper and plastics as well as cosmetics, rubber, food and glass. Figure 2 gives an approximation of the share of each of European consumer sector of lime products, and key functionalities of lime products in these sectors.

[10] Including Precipitated Calcium Carbonate (PCC; which is prepared from lime product).

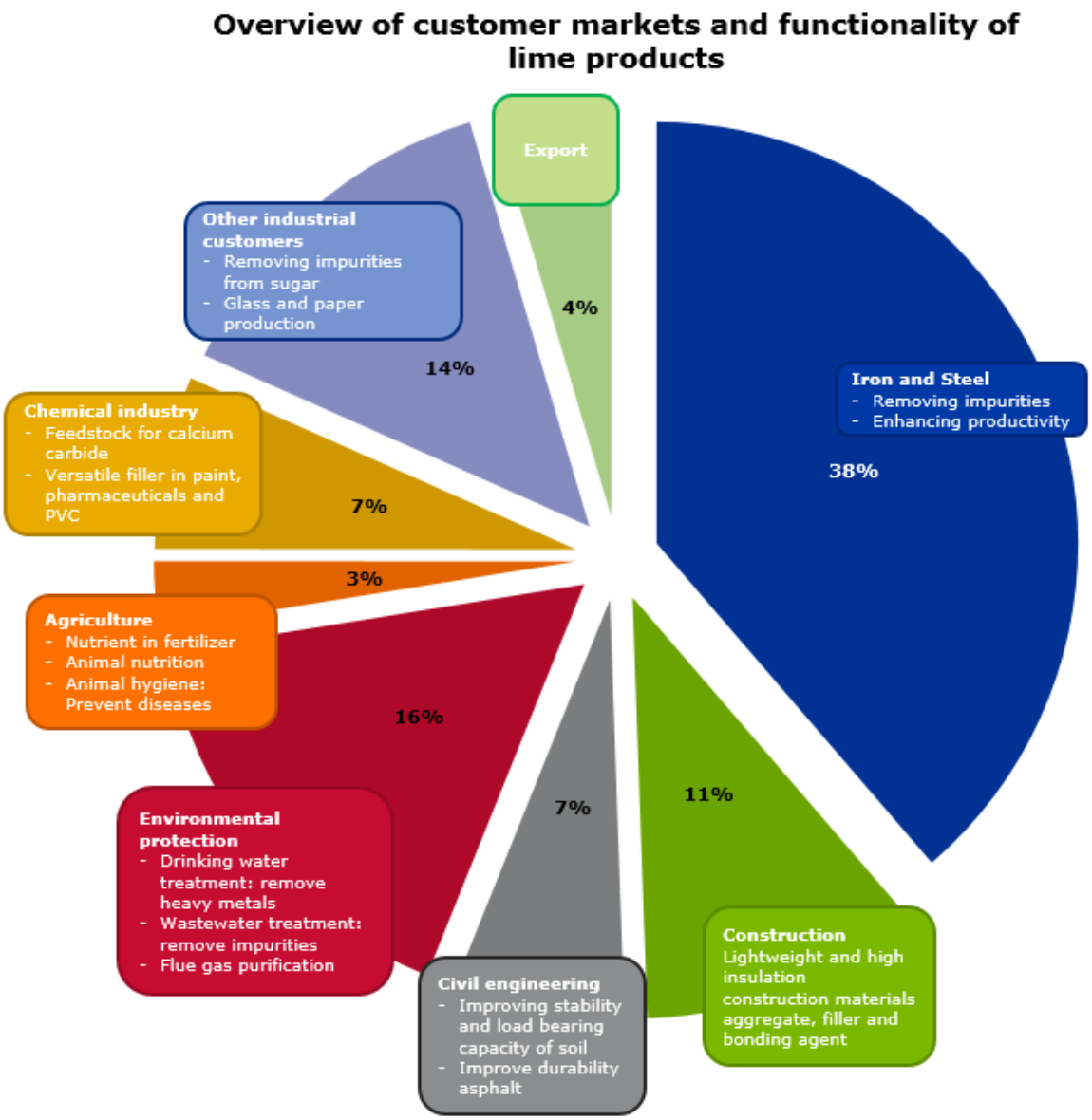

Figure 2: Overview of customer markets (shares are tonnage based for 2012) and functionality of lime products (customer market shares obtained from (EuLA, 2013c); functionality from (EuLA, 2013a)[11].

Lime products are essential in the **steel** manufacturing process. Lime functions as a purification agent by removing impurities such as aluminates, silicates, sulphur and phosphorous through slag formation. Lime products also protect refractories and quicklime is used to improve the productivity of the sinter belt. In the production of cast iron and non-ferrous metals, lime products perform a similar purification role as in the steel manufacturing process.

Lime products are used as filler and bonding agent in building materials in the **construction sector**, for example in light weight construction materials and construction materials with high thermal insulation capabilities such as autoclaved aerated concrete, in sand lime bricks and in mortar.

[11] The share for export might be too high; probably companies that have contributed to EuLA's economic survey have considered intra-EU trade as export (EuLA, 2013a).

Lime products are used in soil treatment at **civil engineering** projects. It can be used to dry wet soil and to provide stability and durability of clay in the soil. It can save time and money on construction projects. Furthermore, hydrated lime is used to improve the durability of asphalt. The addition of 1-1.5% of hydrated lime to hot mixed asphalt increases its durability (EuLA, 2011)[12], leading to an increase of the lifetime of around 25%. An LCA, taking this 25% increase of the life time into account (EESAC, 2012), concluded that by adding 1.5% hydrated lime[13] to hot mixed asphalt total primary energy consumption is reduced by 43%, and greenhouse gas emissions are reduced by 23%[14].

For **environmental protection**, lime products are used in water treatment to remove impurities. In drinking water, lime products help to adjust the pH, water hardness, and to remove naturally occurring heavy metals. In addition, lime is used in flue gas treatment to neutralise acid gases such as sulphur dioxide, hydrogen chloride and hydrogen fluoride. Innovative "High Surface Hydrates" – with other ingredients - feature a large active reaction face and are therefore highly effective. They are applied to various flue streams in industry to effectively capture pollutants like HCl, dioxins, furans and (some) heavy metals.

In **agriculture,** lime products can be used in nitrogen and phosphate containing fertilizers. Lime products are blended in as secondary nutrients. Lime products are an important material for the production of animal nutrition products. The calcium phosphates included in these products are manufactured by adding lime or limestone to phosphoric acid. Lime products are also used in animal hygiene. It is used to sanitize farm environments, preventing the outbreak and spread of diseases.

In the **chemical industry**, calcium carbide is created by reacting lime with carbon. Conventional use includes the production of welding gas, and pig iron and steel as well as in agriculture and chemicals. Precipitated Calcium Carbonate (PCC), made from lime with a very high purity, is used for example as filler and coating in paints and PVC components in the chemical industry. Its crystal morphologies, size and coating can be tailored to improve the performance of these products.

[12] "The field experience from North American State agencies estimate that hydrated lime at the usual rate of 1-1.5% in the mixture (based on dry aggregate) increases the durability of asphalt mixtures by 2 to 10 years, that is by 20 to 50%." "(…), the French Northern motorway company, Sanef, currently specifies hydrated lime in the wearing courses of its network, because they observed that hydrated lime modified asphalt mixture has a 20-25% longer durability."

[13] Based on dry aggregate.

[14] Expressed per functional unit; the functional unit is "one French lane kilometre of road surface (wearing layer) with a width of 3.5 meters (…) and a functional life of 50 years (…)". Numbers refer to the base case.

Lime products are used in the production of **paper** for coating and filling of paper[15], for neutralisation and purification of water, and as reactant[16]. Lime products are also used as a constituent in the production of **glass**. Lime products are also used in the **sugar** refining process.

Although the sector is relatively small, this overview makes it clear that lime is key to many other industrial sectors.

2.3 Innovations

Text Box 2: Patents in the European Lime Industry

An analysis of patents filed by European lime producers between 2005 and 2011 shows that the top 5 applicants patented approximately 83 inventions. These inventions are mainly related to water and sludge treatment, construction and flue gas treatment (EuLA, 2013a).

We can classify the filings of the lime producers in 8 major markets of applications in addition to the lime manufacturing itself .The inventions related to water, sludge and waste treatment, including polluted soils (WST) represent 18% of the applications, closely followed by the construction market segment (CST – 17%) and flue gas treatment (FGT – 14%). Environmental segment – i.e. WST and FGT - represents more than 30% of the filings. Lime manufacturing (MAN) follows then pulp and papers (PAP), agriculture (AGR) civil engineering (CIV) and metallurgy (MET) individually representing 6% or less. Other markets like glass, aints or "unclassified" (OTH) is the major segment with 24%.

Text Box 3: Concrete with Reduced CO_2 Impact - Lime and Hemp in Concrete

Hemp lime concrete is produced as an insulating, phase change, breathable building material made of lime based binder and hemp shiv products. The use of a lime binder allows the inclusion of organic materials (hemp) in concrete, which reduces the CO_2 footprint of the concrete (EuLA, 2013a).

Text Box 4: Dust Minimization from Lime Products

Innovations in the lime sector have resulted in lime products with 90% lower dust emissions compared to conventional lime products. Designed for civil engineering and the construction market, these products have a lower impact on the environment (EuLA, 2013a).

[15] In the form of PCC.
[16] Reactant to recausticize "green liquid" into "white liquor".

Text Box 5: Metal Recovery Using Lime Products

Innovative processes have been designed in which lime products are used to aid in the recovery of valuable metals. In these processes, lime products are used to remove hydrocarbons from metallurgical residues and metal containing sludge, improving the recovery potential of these metals (EuLA, 2013a).

Text Box 6: Application of lime: Lime in the Ecoloop Process

A German lime company is involved in the "Ecoloop" project. Ecoloop aims at producing pure syngas without any flue gas emissions. The gas is produced from shredded material from the automobile industry, sorting residues and rubber parts that have not been pre-processed. Lime is added as the transport medium, pollutant-bonding material, and catalyst. After purification, the gas is directly available for thermal or material utilization or electricity production. The entire process is an economical and efficient closed system, which is referred to as the Ecoloop.
The syngas can also be used instead of natural gas in the lime productions and improves the quality of the lime. In 2012, the Ecoloop project won the prestigious German Innovation Award for Climate and Environment.
(Ecoloop, 2013) and (EuLA, 2013a)

Text Box 7: Improving the application of lime: Lime Audits

To optimize use of lime, some companies have established expert teams, who conduct a Lime Audit to locate potential shortcomings in lime handling and day-to-day operational use by the local operators.

2.4 Market developments

As became clear in the previous paragraph, other energy intensive industry are important customers of the lime industry and consequently, lime industry development is closely dependant on the developments in those sectors. What do their energy and low carbon Roadmaps 2050 say about the impact of energy and climate on their prospects in Europe? The answer is summarized in Figure 3.

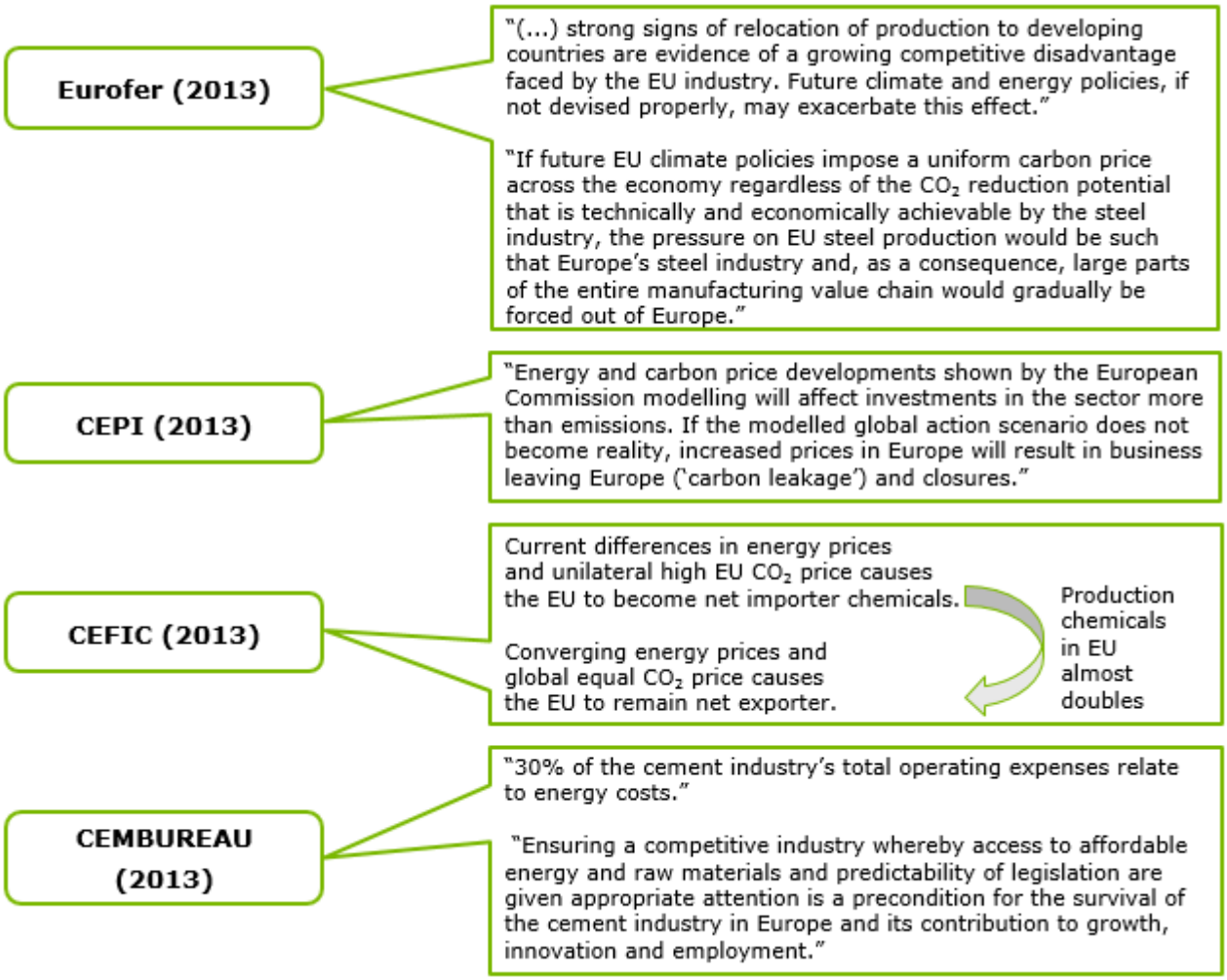

Figure 3: Quotes from energy and low carbon Roadmaps from important client sectors for the European lime industry.

The quotes from the Roadmaps of key customer sectors for the European Lime industry indicate that the European production of steel, cement, paper and chemicals is not to be taken for granted. Under certain energy and climate policy conditions, these industries could relocate their production, significantly reducing the European demand for lime products.

3 Production process of lime products

This section describes the lime production process from raw material extraction to final product. This includes an overview of the different kilns and their distribution in the EU-27.

Most lime producing companies are vertically integrated, which means they are involved in all steps in the production process.

The lime production process is summarized in Figure 4 and discussed below.

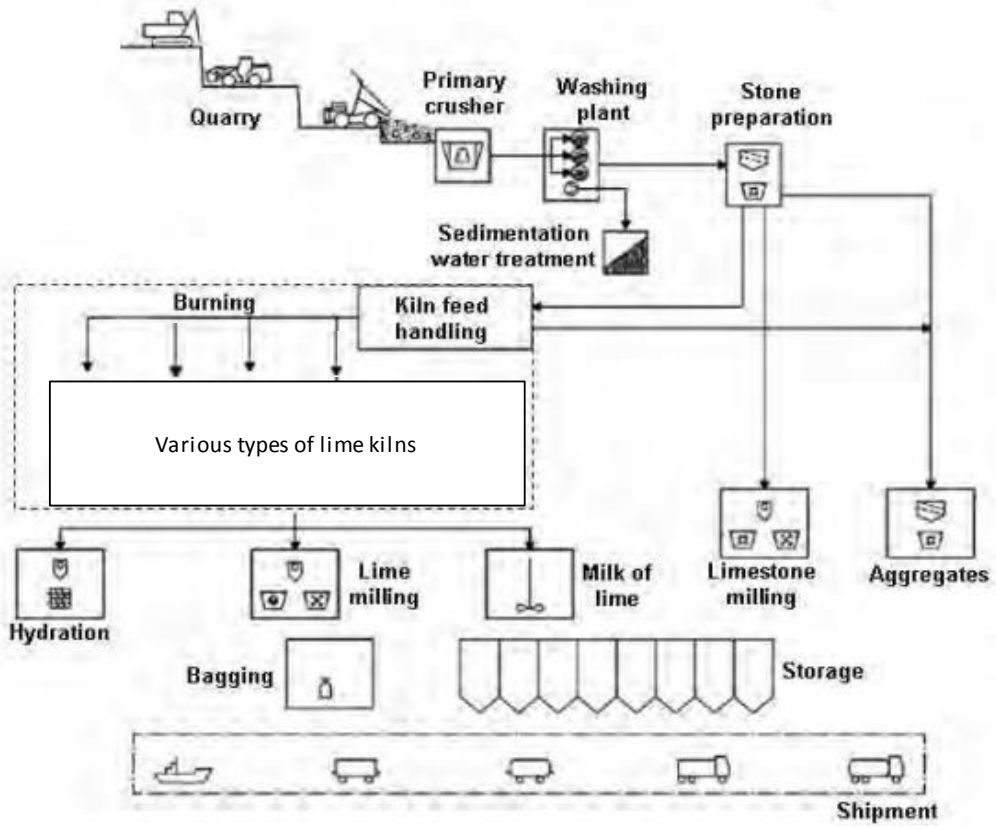

Figure 4: Schematic representation of the production process of lime, adjusted from (JRC, 2013 (BREF))

Step A: Mining and hauling in the quarry

The feedstock for lime production is calcium carbonate and/or calcium magnesium carbonate, which is extracted from quarries and occasionally from underground mines. Calcium carbonate is used to produce lime and calcium magnesium carbonate is used to produce dolime. Calcium carbonate can be found in chalk, limestone and marble whereas dolomitic calcium carbonate can only be found in dolomite. Limestone is a common stone. However, it is rare to find deposits with the right quality and magnitude in a convenient location (EuLA, 2013a).

The first step in lime production is the removal of the topsoil and overburden, which consists of the soil, clay and rocks on top of the calcium carbonate deposits. This is followed by drilling, blasting and extraction of the calcium carbonate containing rock.

Step B: Crushing/sieving

The extracted fragments can be over 1 meter in diameter. These fragments are transported to a primary crusher which reduces the grain size. After the primary crusher, additional crushing and screening takes place until the desired grain size is achieved. Different types of kilns can process different grain sizes, also referred to as granulometries. In a small share of the plants, the final product from the crushers is washed. Crushed limestone is also used as an aggregate in the construction sector, for example in asphalt or concrete.

Figure 5: The trucks tip the limestone into a large primary crusher which usually relies on either impact or compression to break the rock (EuLA, 2013b).

Step C: Calcination

After the stone preparation follows the calcination step, also referred to as 'lime burning'. Lime and dolime are produced in lime kilns, where temperatures of 900 to 1200°C are used in a thermal decomposition process (Ecofys, 2009). CaO or $CaMgO_2$ and gaseous CO_2 are formed according to the following formulas:

- $CaCO_3$ (solid) + energy → CaO, (solid) + CO_2 (gaseous) (lime)
- $CaMg(CO_3)_2$ (solid) + energy → $CaMgO_2$, (solid) + 2 CO_2 (gaseous) (dolime)

In most cases, the decomposition is incomplete.

There are six main types of kilns which are used for lime production, which can be grouped in two categories: vertical kilns and horizontal kilns. These are summarized in Table 2.

Table 2: Different Types of Kilns in the EU-28 (Schlegel, 2013)[17].

Kiln Orientation:	Kiln Type:	Number of Kilns (2013):
Horizontal	Long rotary kiln (LRK)	14
	Rotary kiln with pre-heater (PRK)	20
Vertical	Parallel flow regenerative kiln (PFRK)[18]	183
	Annular shaft kiln (ASK)	67
	Mixed feed shaft kiln (MFSK)	86
Other kiln (OK)		99
Total		469

The other kiln (OK) type contains a wide variety of kiln types. The JRC mentions 10 types, for example double-inclined shaft kilns, travelling grate kilns and rotating hearth kilns.

Ninety per cent of the kilns has a capacity between 10 and 500 tonnes per day (JRC, 2013 (BREF)).

Vertical kilns are generally more energy efficient with regards to fuel consumption. The most energy efficient kiln is the PFRK, which is used to produce quicklime as well as dolime. Horizontal – rotary - kilns typically have a higher production capacity than PFR kilns, and are capable of burning smaller stone feed sizes than PFR kilns. They are, however, less energy efficient and their energy use is 60% to 120% higher than PFR kilns (EuLA, 2012). They are often used to produce specific products, or, in combination with vertical kilns, when the priority of the operator lies with maximum utilisation of the limestone deposit.

Text Box 8: Reactivity of the lime product

The intended end-use of the lime product determines the desired *reactivity* of the lime product. For example for drinking water treatment, lime products with a low granulometry (small particle size distribution) and a high reactivity are used. For soil stabilisation, lime products with a higher granulometry and reactivity are used.

The reactivity of the lime product is a result of the burning temperature and time, the crystalline structure of the limestone, the impurities of the limestone and the kiln type and fuel. Reactivity is a measure indicating the speed with which the temperature rises from 20 to 60°C in a mixture of lime and water under standardised conditions. A decrease of the reactivity of a lime product is a consequence of the reduction of the surface and the porosity of the lime. The reactivity of the lime product can be expressed as soft burnt (high reactivity), medium burnt (medium reactivity), hard burnt (low reactivity) and dead burnt (no reactivity) (JRC, 2013 (BREF)).

Most lime production plants employ several types of kilns, in order to optimally use the calcium carbonate deposits and to produce different types of lime products (EuLA, 2013a). Lime and dolime are usually processed in the same kilns.

[17] Numbers relate to EU-28 (including Croatia). There is uncertainty concerning the numbers of MFSK and OK operated in Greece and Bulgaria (especially for the very small lime producers).
[18] Standard and fine lime kiln.

Step D: Kiln downstream

The lime from the kiln, often referred to as run-off-kiln lime, requires additional processing. In a first step, the fine fraction run-off-kiln lime (smaller than 2 to 3 mm) is separated. This fraction contains impurities from the source material as well as from the fuel and is considered 2nd grade quality.
The remaining product is crushed in order to obtain pebble lime, which has diameters from for example 2 to 12 mm or 12 to 40 mm and a residual lime, with diameters from 0 to 2 mm. The remaining product is further ground using ball mills, roller mills or high pressure mills.

Quicklime is stored in dry conditions with limited exposure to fresh air, since it readily reacts with moisture in the air to form hydrate.

Step E: Hydration (optional)

Quicklime and dolime may be hydrated by using a slaker in order to produce slaked lime and slaked dolime. This is an exothermic reaction which generates 1.14 MJ per kg CaO (JRC, 2013 (BREF)). The following formula describes this reaction:

- $CaO + H_2O \rightarrow Ca(OH)_2$ + energy

When more water is added to hydrate, so called ‘milk of lime’ is produced.

4 A Competitive EU Lime Industry

This section provides an analysis of the competitiveness of lime production in the EU-27. This is based on a breakdown of EU and non-EU production costs, taking into account the effects of carbon pricing. This results in an indication of the trade vulnerability of the EU lime production sector.

4.1 EU production overview

In 2006, EU-25 lime production was 16.3% of global lime production (EuLA, 2013a). Historically, today's important lime assets were owned by large industrial conglomerates. During the last three decades, many conglomerates divested from these assets, leading to the formation of – somewhat - larger group of smaller companies that have lime production as their core business. The five biggest companies own around 40% of all installations in the EU (EuLA, 2013a). The vast majority of the other installations are Small and Medium Enterprises, often single plant, family-owned enterprises, typically with smaller production capacity.

Lime products are produced in most of the EU countries, as is shown in Figure 6. Recent developments might have changed the picture.

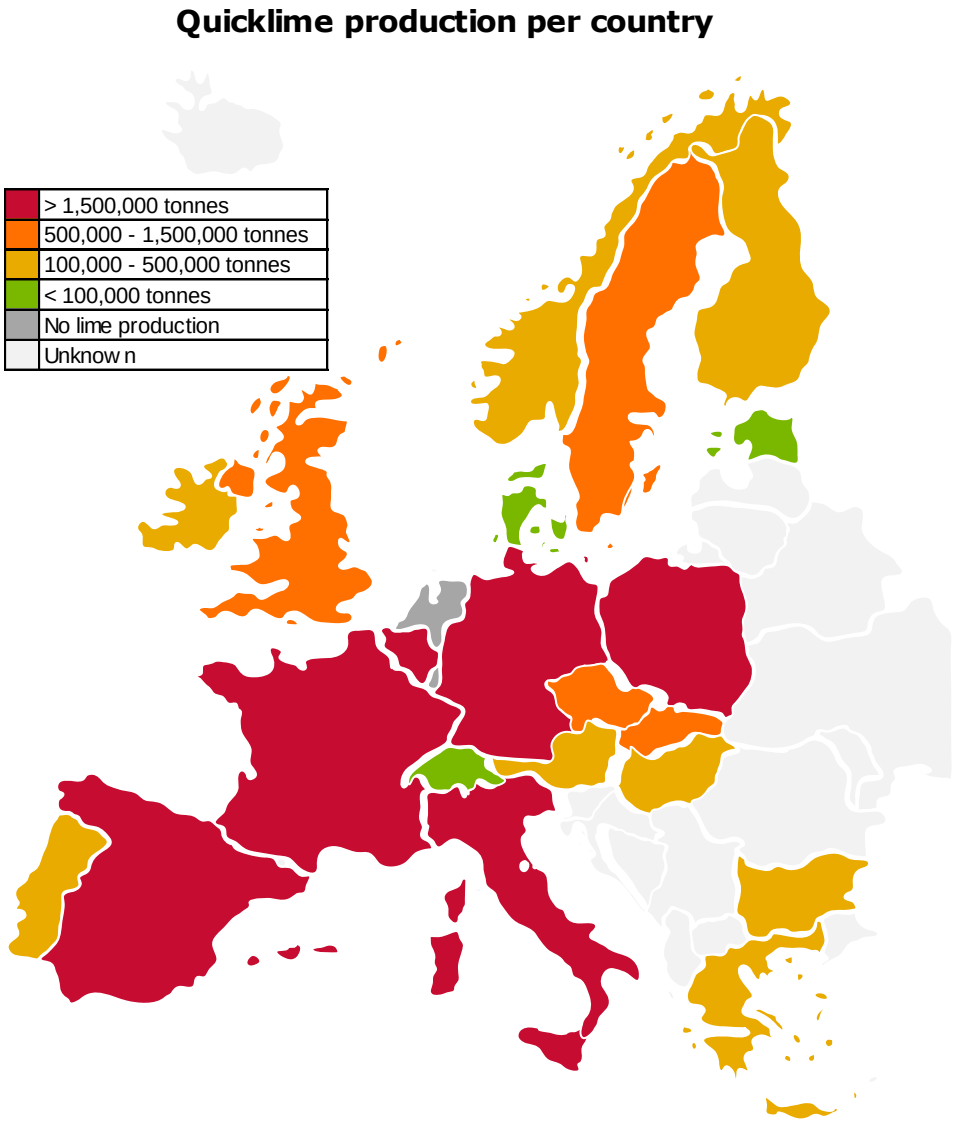

Figure 6: The colours on this map provide an indication of the quicklime production per country in 2011. Red indicates a quicklime production of over 1,500,000 tonnes, orange between 500,000 to 1,500,000 tonnes, yellow between 100,000 and 500,000 tonnes and green below 100,000 tonnes. Dark grey indicates no lime production and light grey indicates no data is available (EuLA, 2013a).

These installations together produced around 22 Mtonne of quicklime in 2011[19] (EuLA 2013). Since 2006, EU production of lime has declined (Eurostat, 2013), due to the crisis.

[19] This number is based on information provided to EuLA by its member companies. Non-member company data is excluded. The scope is not exactly EU-27 production. The number does not include (agglomerated) dolime. Dolime adds 11% to this production tonnage (Prodcom 23523030/23523050 for 2011 (Eurostat, 2013)).

4.2 EU production costs

In 2008, EuLA assigned economic consultant NERA to study the potential impacts of the EU ETS on the European Lime Industry (NERA, 2008). In this report, the cost of producing lime is assessed, based on 2006 data for the production of 3 mm lime[20]. The study finds that:

- Production costs vary over the different types of lime kilns, between €55/tonne lime to more than €70/tonne lime[21].
    - Several factors contribute to the variation in long-term marginal production costs including capital costs:
        - Energy costs[22] represent 40%[23] of the production costs and depend on the energy efficiency of the kiln, as well as on the type of and price of fuels. Kilns may use different fuels, and prices may vary regionally to some extent. Because of the variability of fuel prices, NERA suggested that these costs are expected might be the most variable of the costs categories, although their report did not present data on costs over multiple years.
        - Raw materials costs account for 17% of the production costs, partly depending on the distance from the geological occurrence of the raw materials.
        - Capital/depreciation costs amount to 7% of the production costs[24]. In general, companies ascribe a relatively low capital and depreciation costs of around €4/tonne lime to their existing capacity[25].
        - Other costs amount to 37% of production costs. These costs include operation and maintenance, labour costs, and company overheads.
        - Some extremes of high- and low-cost producers often reflect special circumstances, including different standards of lime purity and sources and transport costs for raw materials. This provides an indication that, rather than a single EU lime market, current lime production is segmented into several different product and geographic markets.
- The costs ascribed to *existing* capacity should not be taken as an indicator of the capital cost of *new* equipment. It is reasonable to assume that operating costs of new production facilities may be lower than in much of existing capacity, whereas prospective capital costs would likely be higher than the amount ascribed to existing equipment. Currently, in the EU there is substantial spare capacity (EuLA, 2013a), negatively impacting the business case for new investments.

The study investigated the costs of carbon pricing on EU production costs, and concluded that, in the absence of free allocation of allowances, a carbon price of €30/tonne CO_2 adds €32/tonne quicklime to the production costs, an increase of more than 50%. Margins for EU lime production – including attributed capital costs – are between €9-12/tonne lime (long-term) or – excluding capital costs - €14-16 per tonne lime (short term).

[20] It does not include dolime, nor other grades of lime that require additional processing. The analysis has not been updated.
[21] The kiln types producing the majority of the quicklime are included in these numbers (but not all kiln types). Other variations are equally significant or even more significant than the variation between average costs for individual technology types.
[22] CO_2 costs have not been taken into account.
[23] (JRC, 2013 (BREF)) reports the same order of magnitude: "(…) the costs of fuel per tonne lime can represent 30 to 60% of the production costs."
[24] For new plants, these costs are expected to be higher.
[25] Interpreting this is complicated by the fact that conventions for allocating fixed costs to production are likely to vary between companies.

4.3 Production outside the EU

The study on the impact of the EU ETS on the EU lime industry (NERA, 2008) also mapped the non-EU production cost. This assessment was based on actual project estimates and studies in the Former Soviet Union and North Africa (further indicated as non-EU in this paragraph). Data provided by EuLA members indicate costs of production at *existing* capacity in non-EU locations, excluding capital costs, in the region of €32-47 per tonne lime (costs increase €3-5 per tonne lime if capital costs are included):

- A key reason for the lower production costs in non-EU locations are lower energy costs, estimates of which range between €5-20 per tonne lime depending on location.
- Where detailed estimates are available, labour costs also appear to be significantly lower in several locations, while some estimates also indicate substantially lower raw material and overhead costs.

The production costs for *new* capacity are close to production costs for *existing* capacity[26].

[26] (NERA, 2008): "On the one hand, the costs of some items, notably raw materials and fuels, may be lower than that of existing capacity, reflecting more efficient equipment and possibly more advantageous location of production. On the other hand, long-term costs include capital costs, estimates of which vary in the range of €5-11 per tonne lime. Overall long-term costs, including investment costs, vary in the range of €32-47 per tonne lime."

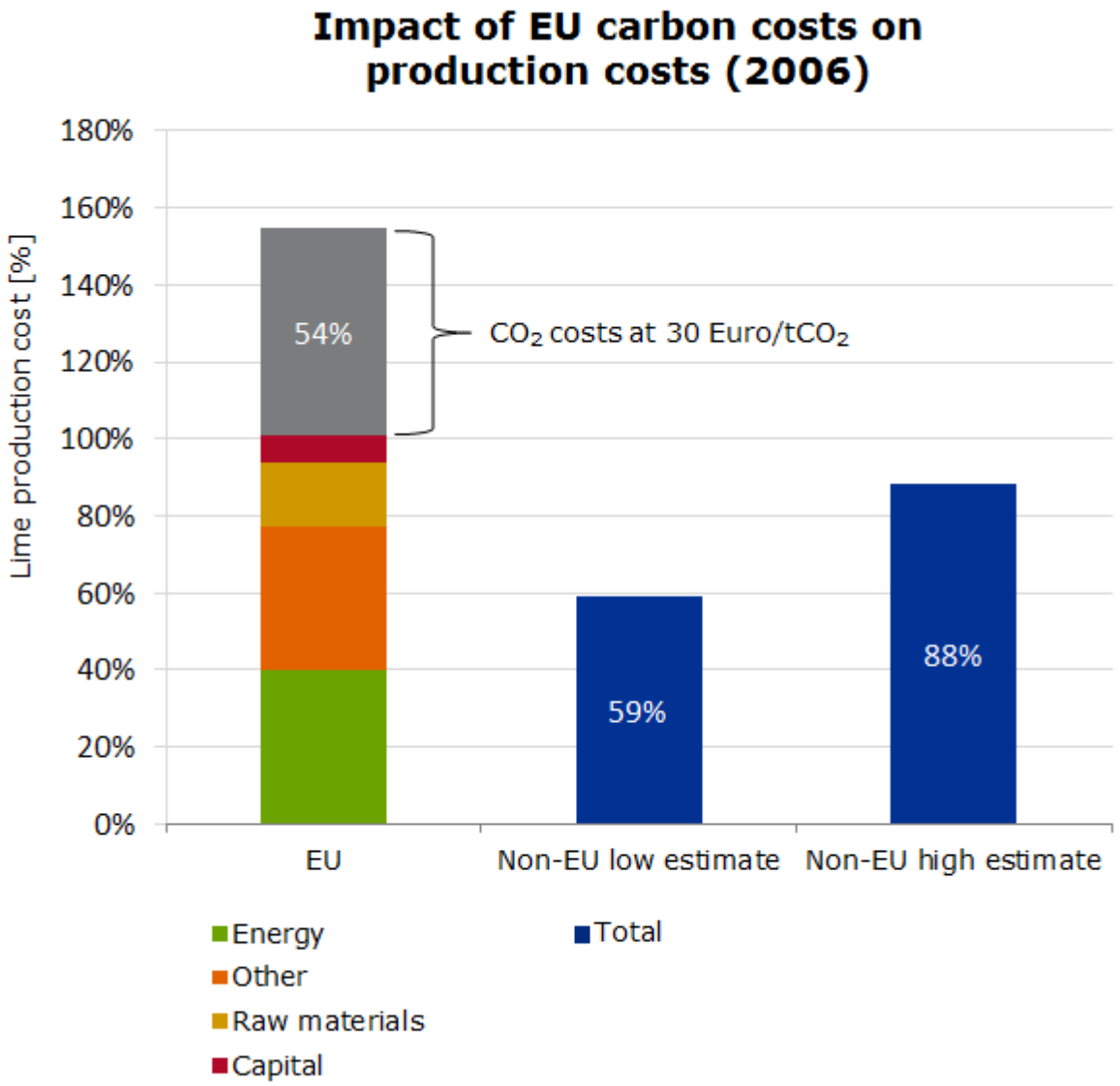

Figure 7: Impact of EU carbon costs on production costs (2006; based on (NERA, 2008)). Impact of carbon costs in the absence of free allocation of allowances and without transport costs[27].

Figure 7 clearly shows that non-EU production costs are already lower than EU production costs, and adding a unilateral EU carbon price increases the difference. In the next paragraph, consequences of this increasing difference will be assessed.

[27] For the non-EU low estimate two low numbers have been added. For the non-EU high estimate two high numbers have been added.

Table 3 gives more background information on more recent differences in energy prices between EU and non-EU. The table shows that energy – especially natural gas – is relatively expensive in EU.

Table 3: **End-user fuel prices (including taxes) per source and per region, shown in € per GJ (the majority of prices from 2011 and 2012, none prior to 2010 (NERA, 2013)).**

Region	Natural Gas	Fossil Solid Fuels	Liquid Fuel
Brazil	5	n.a.	10
US	3	2	12
Egypt	3	n.a.	4
India	3	2	7
Russia	2	1	5
Belarus	3	3	8
Turkey	9	3	9
Ukraine	5	2	8
Middle East	<1	n.a.	<1
Maghreb	<1	n.a.	2
EU	9	3	9

The text box below shows the impact differences in energy prices can make.

Text Box 9: Impact of cheap energy sources: US shale gas

Over the last years the wedge between US and EU prices for natural gas has widened. Table 3 shows that US energy consumers currently pay far less for natural gas than their EU competitors. Especially the exploitation of unconventional[1] gas has seriously pushed down the US gas price since 2009 (TD Economics, 2012).

Shale gas clearly had a beneficial impact on the US economy. IHS Global Insight highlights in particular the following contributions (IHS, 2011):

- The lower natural gas prices have resulted in a 10% reduction in electricity costs nationally;
- Lower energy prices increase industrial production by 2.9% by 2017; up to 4.7% by 2035;
- Savings from lower gas prices will add an annual average of $926 per year in disposable household income between 2012 and 2015. In 2035, this would increase to just over $2,000 per household.

Also China and India have begun exploring the potential of shale gas, although the pace of development of China's and India's shale gas resources could be significantly slower than in North America (Nakano, 2012).

The European potential for recoverable unconventional gas is estimated to be in the same order of magnitude as conventional gas resources (IEA, 2012). The import dependency for natural gas in 2035 in Europe would be 86% in a low unconventional gas scenario as compared to 74% in a high unconventional gas scenario (IEA, 2012). Environmental issues related to unconventional gas concern the large volumes of water used, methane emissions and potential pollution due to the chemicals used in exploration. Appropriate attention should be paid to these environmental issues when explorating shale gas in Europe and globally.

The impact of potential unconventional gas development in Europe on the price of gas for Europe is difficult to assess, because the long-term natural gas equilibrium price is determined by many factors, including developments in the demand and supply in other parts of the world. Exploration and production of shale gas in Europe will have a decreasing impact on long-term natural gas prices in Europe. This also holds for an improved natural gas trade infrastructure in Europe and strengthened natural gas trade relations.

In such an international context the EU has to pay particular attention to the availability of energy sources at a price comparable to its main competitors.

4.4 Trade vulnerability

In 2011, exports (~500 kton; ~2% of production) and imports (~300 kton; ~1% of production) of lime products in the EU are more or less balanced (Eurostat, 2013).

The production costs in the EU and outside the EU have been described in paragraphs 4.2 and paragraph 4.3. So far, trade in lime products between EU and non-EU is relatively limited. At increasing carbon costs in Europe this picture could be different. The effect of increasing carbon costs in Europe is clear from Figure 7; carbon costs significantly add to the production costs of lime.
To evaluate the consequences of this increasing difference in production cost between EU and non-EU countries, the costs to transport lime from outside the EU to EU needs to be taken into account[28]. These costs are high relative to other production costs and relative to the overall value of lime products (NERA, 2008); uptake of water during transport needs to be prevented to keep the product within specification. Recently, EuLA has asked economic consultant NERA to make this comparison (NERA, 2013). The approach focuses exclusively on[29]:

- Differences in energy costs;
- Carbon costs (both for process and combustion emissions);
- The additional costs associated with transporting lime from a kiln in a non-EU country into the EU.

The difference in the costs of energy plus carbon are compared to the costs of transporting lime from non-EU countries to arrive in the EU either via land (rail and road) or via sea, or via a combination of the two. (NERA, 2013)'s summary notes that as an assessment of competitiveness its analysis is partial:

- "This analysis provides a partial understanding of the potential threat posed to EU lime producers by foreign competitors, as a result of differences in selected underlying costs. Because other costs, such as labour and capital costs, may also be different between EU and foreign regions, our analysis may understate the potential cost differences that constitute the threat from foreign sources." (NERA, 2013).
- "On the other hand, because our analysis focuses on *current* differences in costs, it may be that the threat from foreign producers is already reflected in existing trade flows between the EU and other regions. Insofar as current trade is relatively limited, this may indicate that the potential threat suggested by our analysis is mitigated to some extent by other costs or barriers to foreign imports. These barriers could include differences in quality, the value of the long-term business relationships, the lack of available spare production capacity, and/or concerns about the stability of cost differences, which might make foreign producers reluctant to invest in "dedicated" export capacity. The latter concern might be overcome if domestic consumption were expected to grow quickly enough to absorb the new capacity in case the EU cost differential were reduced" (NERA, 2013).

The analysis assesses two scenarios, of which the basics are summarized in Table 4.

[28] The effect on export is ignored here for simplicity reasons. The effect of increasing the EU production costs on export is straightforward: It would reduce the impetus for export.
[29] This is no comparison of the full costs of lime production in the different countries.

Table 4: Scenario assumptions used in Figure 8 and Figure 9.

Scenario:	Fuel Mix:	EU Carbon cost[30]:	Transport cost:
Central Case	EU: Average fuel mix for lime production Non-EU: Average for overall industrial production	€5/tonne CO_2	
Increased Threat	EU: Average fuel mix for lime production Non-EU: Cheapest fuel in each country	€15/tonne CO_2	Reduced costs for sea transport

Locations outside the EU for which differences in energy costs and carbon costs exceed transport costs

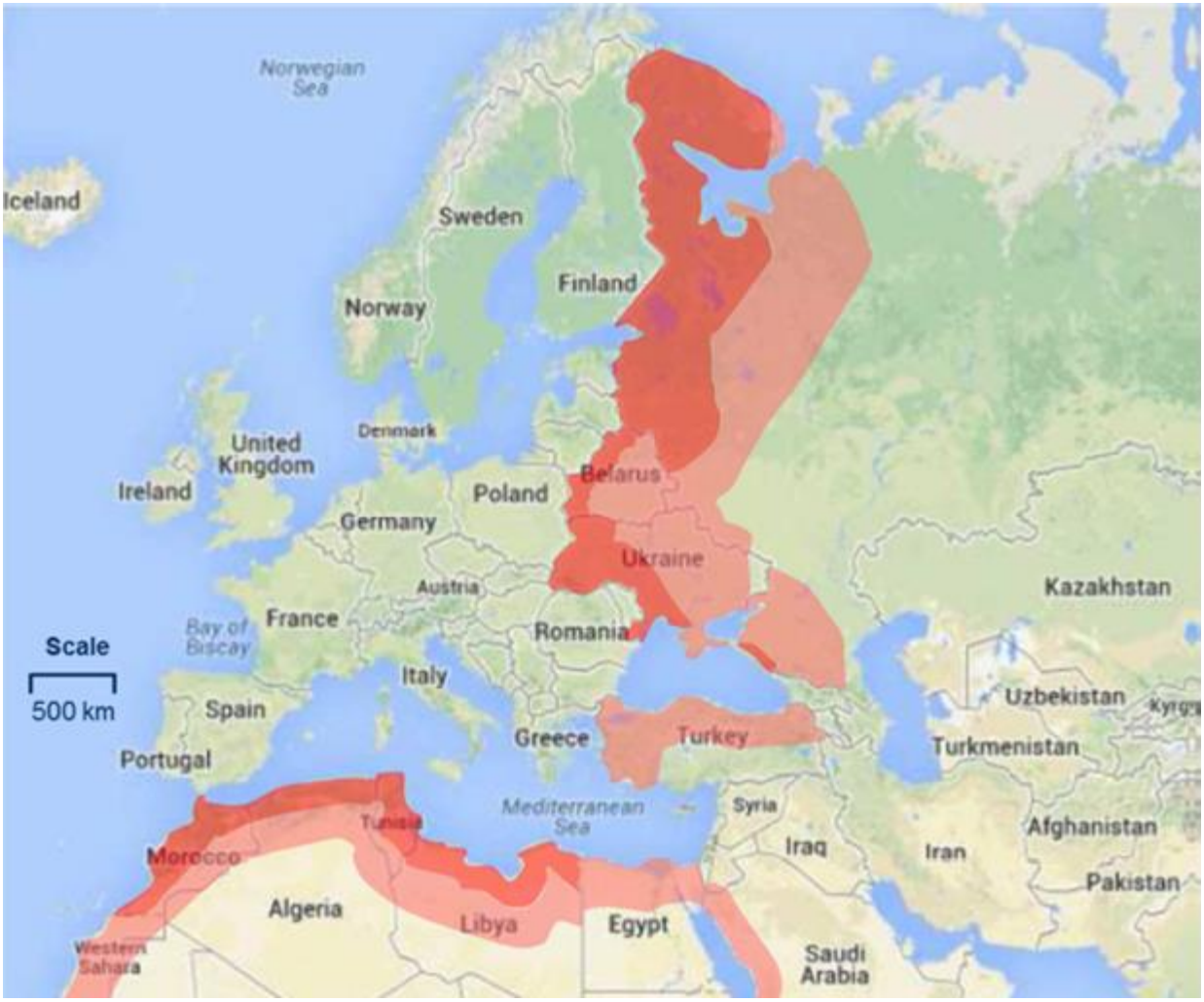

Figure 8: Locations outside the EU for which the estimated differences in energy costs and carbon costs (compared to the EU) exceed transport costs from the kiln to the EU border. The darker red shaded zone represents the area from within which a lime kiln, situated outside the EU, might be able to transport to the EU for the same, or lower costs (taking into account transport, energy and carbon costs) as an EU-based lime kiln located on the border under the Central Case scenario. The lighter red shaded zone represents the additional area for the Increased Threat scenario (NERA, 2013).

[30] No carbon price in non-EU; no free allocation of allowances.

Locations within the EU to which it might be economical to import lime from outside of the EU, taking into account the differences in energy and carbon costs between the exporting (non-EU) countries and the EU and comparing this difference to the transport costs from the EU border

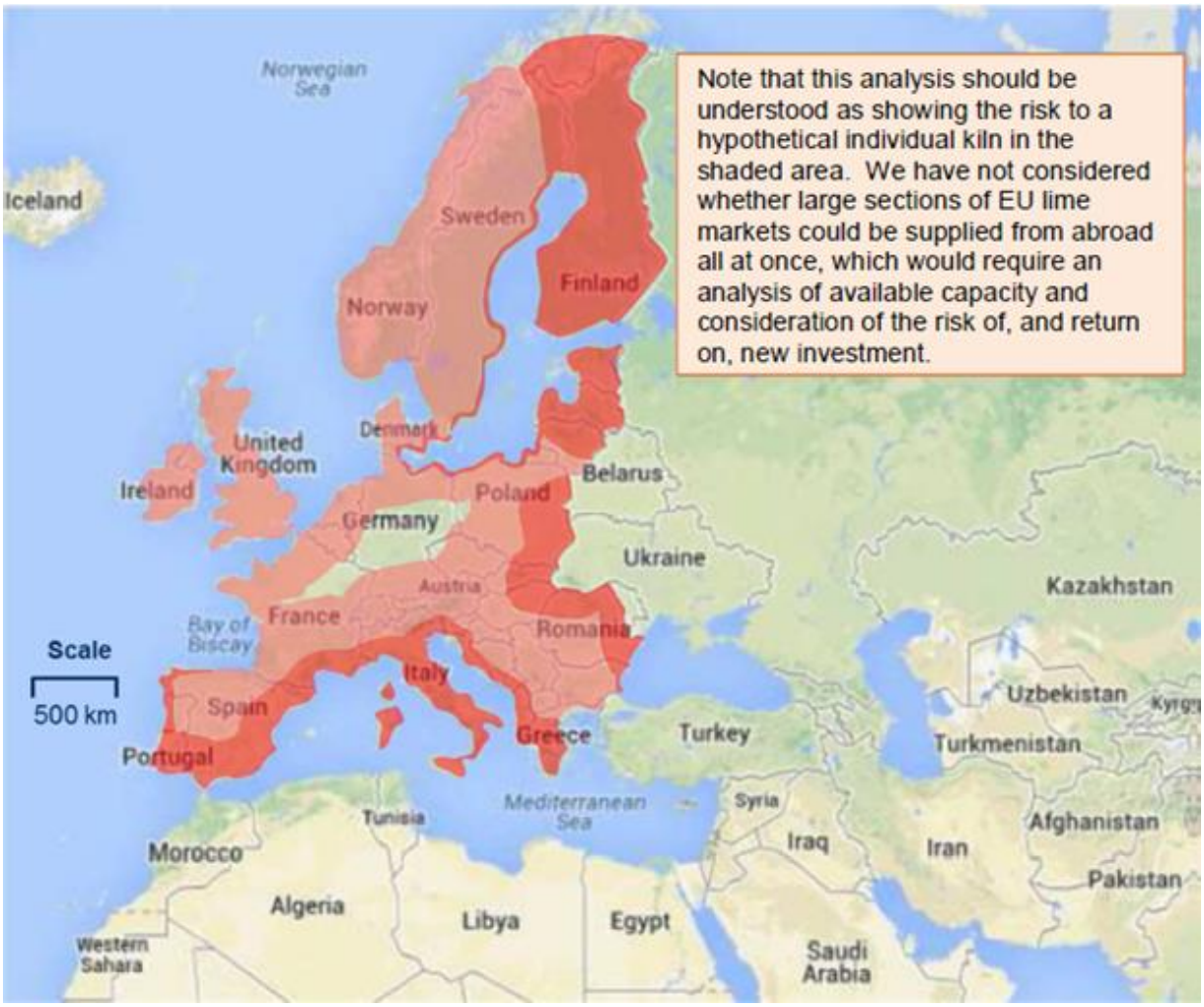

Figure 9: Locations in the EU to which it might be economical to import lime from outside of the EU, taking into account the differences in energy and carbon cost between the exporting (non-EU) countries and the EU and comparing the differences to the transport costs from the EU border. The darker red shaded zone represents the Central Case scenario; the lighter red shaded zone shows the additional area under the Increased Threat Scenario (NERA, 2013).

Under the "Increased Threat scenario", (NERA, 2013) found that Brazil, the US and India did not pose a competitive threat to the EU based on the comparison of energy, carbon and transport cost. This would – depending on country and scenario – change at carbon prices around €25 - €65 per tonne CO_2[31].

[31] More detailed information in (NERA, 2013). The same limitations to the interpretation as mentioned above Table 4 still apply.

To illustrate the relative impact of differences in carbon prices and differences in energy prices:

- A carbon price of €30/tonne CO_2 adds €32/tonne quicklime to the production cost (refer to paragraph 4.2);
- A difference of in the price for natural gas of €8/GJ (the highest difference in Table 3) leads – with the average fuel use for the production of quicklime of 4.25 GJ/tonne quicklime (paragraph 5.1.1.1) – to a difference in production cost of €34/tonne quicklime;
- A difference in the price for coal of €2/GJ (the highest difference in Table 3) leads – with the average fuel use for the production of quicklime of 4.25 GJ/tonne quicklime (paragraph 5.1.1.1) – to a difference in production cost of €8.5/tonne quicklime.

Of course, the likelihood for loss of competitiveness/carbon leakage differs – amongst others -

- Per market segment;
- Location of the EU kiln and its customers (coastal vs. inland; inland kilns with nearby customers are better protected against foreign imports than kilns at harbours);
- Importance of security of supply and the cooperation with customers/duration of the contract.

It is apparent though that at current carbon prices[32] - in the absence of free allocation of allowances – and current differences in energy prices, some neighbouring countries have energy and transport cost that - in the absence of other differences or mitigating factors - are low enough that they could pose a threat to EU producers. However, other factors are important for a complete evaluation of the risk of relocation of lime production from the EU to non-EU countries.

The availability of deposits which contain sufficient amounts of resources with high chemical purity and the right physical and mechanical properties in neighbouring countries has not been assessed.

[32] Based on the spot EUA daily closing price published by Point Carbon, the average carbon price over the first 8 months of 2013 was €4.28 (NERA, 2013).

5 Energy Use and Emissions

5.1 Current energy use and Emissions

The production of lime requires energy and leads to CO_2 emissions. Energy is mainly used in the calcination step. This chapter provides details on the energy consumption and CO_2 production in the lime production process and gives an overview of abatement measures[33].

5.1.1 Current energy consumption

5.1.1.1 Current heat consumption

The current (2010) average fuel consumption[34] was 4.25 GJ/tonne quicklime.

Since calcination is the most energy intensive step in the lime production process, the energy efficiency of the kiln operations has a large impact on the overall energy efficiency and hence the emissions of lime production.
The energy efficiency of the kiln depends on the kiln type, but also on:

- The desired lime product;
- The grain size (JRC, 2013 (BREF));
- Limestone humidity (JRC, 2013 (BREF));
- Fuel (dry, efficiency, etc.) (JRC, 2013 (BREF));
- Residual CO_2 content in the lime product (JRC, 2013 (BREF));

The theoretical minimum energy consumption in the kiln is 3.18 GJ per tonne CaO produced (Oates, 1998)[35]. This number assumes complete conversion of limestone into lime. In reality, not all limestone is converted to lime, and lime products contain impurities. For quicklime with a free CaO content of 94.5w% and a free MgO content of 0.9w%[36], this value would become 3.03 GJ/tonne quicklime[37]. Limestone typically contains 1% of water (Schlegel, 2013) which evaporates in the kiln[38]; this requires 0.04-0.05 GJ/tonne of lime[39].

[33] Figures on production, energy use and CO_2 emissions have been based on incomplete data gathered from industry. Assumptions have been made and different sources have been combined. The population of this data is not always the same, effects caused by Lime Kiln Dust and production of the Ultra low Carbon dolime are ignored and differences in free CO_2 are ignored. Therefore, these figures are to be considered as estimates. The figures in this chapter relate to the energy- and carbon-intensity of producing lime products, not to their absolute values, as the production of lime products in EU has not been projected. Projections of the development of product capacity/capacity replacement rates have not been used in the generation of the figures.
[34] Based on (EuLA, 2012), giving data for 2010. Scope of data includes fuel preparation, calcination/sintering and flue gas treatment. Not all EU lime kilns are included in these numbers. Due to differences in product quality/specification and effects of the incomplete data, no reliable number for the average heat consumption for the production of dolime and sintered dolime can be determined from (EuLA, 2012). Quicklime production represents – by far – the biggest share of energy consumption.
[35] This is the heat of dissociation of calcite (most stable polymorph of calcium carbonate) relative to 25°C.
[36] (Oates, 1998) gives a heat of reaction of 3.03 GJ/tonne MgO for the formation of MgO from $MgCO_3$.
[37] This value is applicable only to quicklime with the quality mentioned, and should not be seen as a benchmark value.
[38] Or in a preceding drying step; for soft limestone of chalk, the moisture can rise up to 10-15%, thus leading to a significant increase in energy demand.
[39] Based on the thermodynamic properties of water, all at 25°C.

Table 5 shows the range of heat use for the six most important types of kilns (JRC, 2013 (BREF)). It can be seen in this table that vertical kilns (PFRK, ASK and MFSK) are more efficient than horizontal kilns (LRK and PRK).

Table 5: **Overview of the minimum and maximum heat consumption per kiln type for quicklime production (JRC, 2013 (BREF))**[40]

Kiln orientation:	Kiln type:	Heat use/consumption for quicklime production (GJ/tonne):
Vertical	Parallel flow regenerative kilns (PFRK)	3.2[41]-4.2
	Annular shaft Kilns (ASK)	3.3-4.9
	Mixed Feed Shaft Kilns (MFSK)	3.4-4.7
Horizontal	Long Rotary Kilns (LRK)	6.0-9.2
	Rotary Kilns with preheater (PRK)	5.1-7.8
Other Kilns		3.5-7.0

Figure 10 shows the theoretical minimum energy consumption of lime production in comparison with the range of energy consumption of horizontal and vertical kilns from Table 5.

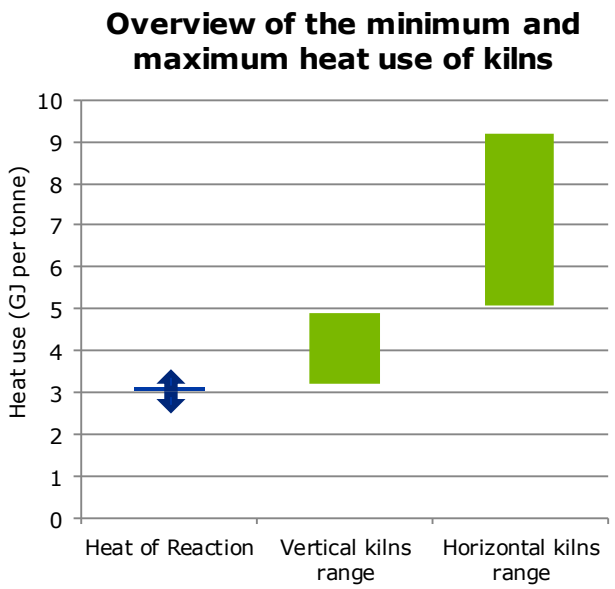

Figure 10: Overview of the minimum and maximum heat use for vertical and horizontal kilns in relation to the theoretical minimum energy consumption for the production of quicklime. The "Heat of Reaction" is based on a mixture of 94.5% CaO and 0.9% MgO; the blue arrows indicate that other compositions have a different Heat of Reaction[42]**.**

[40] In (JRC, 2013 (BREF)) it is unclear whether these numbers cover 80% or 95% of the total energy consumption for lime production. (Schlegel, 2013) clarified that these numbers indeed cover 95% of the total energy consumption for lime production, and that the given heat consumption only relates to the production of quicklime (differently than quoted in (JRC, 2013 (BREF)).

[41] This number is extremely close to the heat of reaction (3.18 GJ/tonnelime; assuming 100% CaO; in reality this percentage is lower). (ERA Technology, 2012) remarks: "However, achieving an energy consumption of 3.2 GJ/tonne is remarkable considering that the theoretical consumption is 3.18 GJ/tonne." Most likely the energy consumption of 3.2 GJ/tonne is realized for lime grades with relatively high concentrations of residual CO_2 content, in which case the theoretical heat consumption would be lower.

[42] Excluding "Other Kilns"; the heat use of kilns also depends on other factors, such as quality and product requirements (refer to start of section 5.1.1.1).

It is illustrative to compare examples of the best energy efficiencies currently achieved by new large furnaces.
Table 6 shows that new large PFRK lime kilns are energy efficient in comparison with kilns/furnaces in other sectors.

Table 6: **Comparison of examples of the best energy efficiencies currently achieved by new large furnaces (ERA Technology, 2012).**

Process:	Energy Efficiency:
Parallel flow regenerative lime kilns	80-90%
Rotary cement kilns with pre-heaters and pre-calciners	68%
Cross-fired regenerative glass melting	49%
Brick kiln	68%
Steel electric arc furnace	70%
Steel re-heating	75%

By far the majority of the energy consumption in the lime production process is heat required in the kiln during the calcination step. This energy comes either from fossil fuels (natural gas, fossil solid fuels and oil) or from waste and biomass. Figure 11 shows the energy use for each of these fuel types (EuLA, 2012).

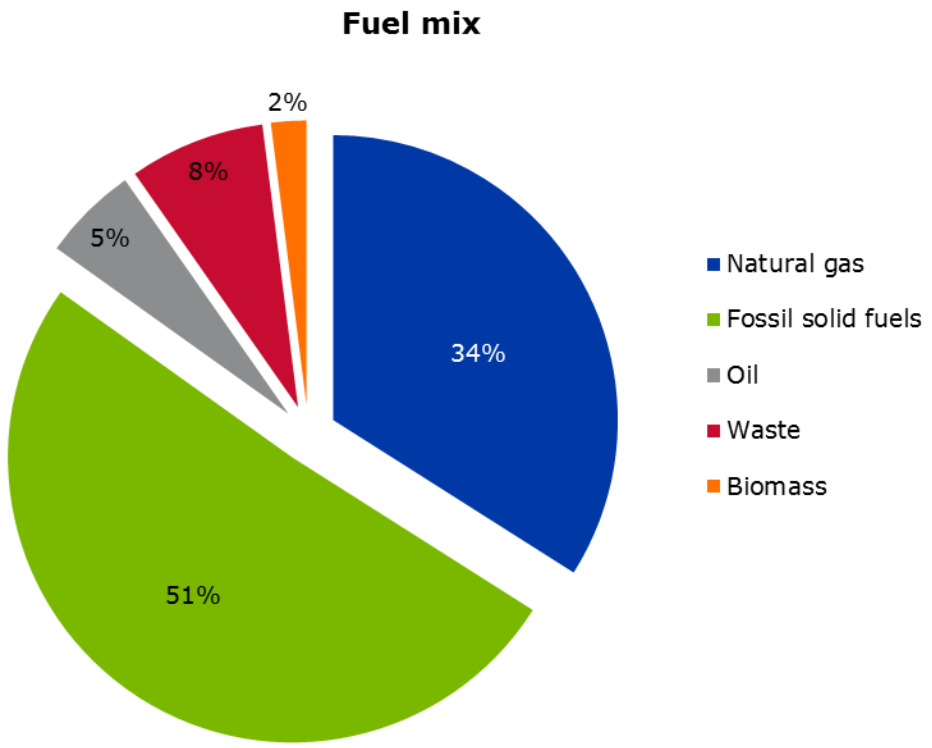

Figure 11: Fuel mix (2010, (EuLA, 2012))[43].

[43] This fuel mix is the weighted average of the fuel mix for each of the three lime products reported in (EuLA, 2012). Weighting on the basis of energy use for each of the lime products. The fuel mix is determined on the basis of incomplete data.

5.1.1.2 Current electricity consumption

The electricity consumption in lime manufacturing is small, in the order of magnitude of ±60 kWh/tonne lime product (around 5% of the total energy use)[44]; this is an order of magnitude estimate based on:

- The ratio 2.8% between indirect induced carbon cost and GVA (EC, 2009). GVA obtained from SBS NACE4 rev 1.1 2652; CO_2 price proxy of 30 euro/tonne CO_2 and the emission factor for power production (0.465 tonne CO_2/MWh) used in the Carbon Leakage assessment (European Commission, 2009). This leads to an electricity consumption of ±70 kWh/tonne lime product[45];
- Electricity consumption as mentioned in the BREF (JRC, 2013 (BREF)): Kiln 5-50 kWh/tonne, hydrating 5-30 kWh/tonne, grinding: 4-40 kWh/tonne[46];
- The electricity consumption as used to derive the LCI (EESAC, 2011): 50 kWh/tonne quicklime (Schlegel, 2013).

5.1.2 CO_2 Emissions

To generate the energy for the lime production process, fossil fuels are burned. The combustion of fossil fuels causes CO_2 emissions. The vast majority of emissions from fossil fuel combustion originate in the kilns. No focus is given in this Roadmap on the CO_2 emissions in other parts of the production process, because of their relatively small size compared to the emissions in the kiln (EESAC, 2011):

- The emissions during the downstream processing and hydration account for around 1.5% of total CO_2 emissions (EuLA, 2013a);
- Emissions during mining and stone preparation account for around 0.7% of total CO_2 emissions (EuLA, 2013a).

The chemical reaction for lime production also leads to the production of CO_2, as can be seen in the formulas shown in chapter 3. In addition to the emissions attributed to the energy consumption of the lime production process, this is also a source of CO_2 emissions. These emissions are constant and amount to 0.785 tonne CO_2 per tonne of lime and 0.913 tonne CO_2 per tonne of dolime (Ecofys, 2009)[47] (in case of complete conversion of limestone and dolomite and no other impurities).

[44] Given the low share electricity related emissions have in the total emissions and the absence of further data availability, this Roadmap has not focused on mapping electricity use, or saving options. The electricity consumption reflected here should therefore not be used as input for policy decisions.

[45] Based on quicklime, slaked lime and hydraulic lime (2006 data).

[46] The electricity consumption for mining and stone preparation represents < 0.7% of the total CO_2 emissions (EuLA, 2013a) and is not further taken into consideration in this Roadmap.

[47] These numbers assume 100% decarbonation of limestone; in reality, lime contains a small fraction of limestone, meaning that actual process emissions are somewhat lower than the mentioned 0.785; likewise for dolime.

The distribution of the different causes for CO_2 emissions is shown in Figure 12.

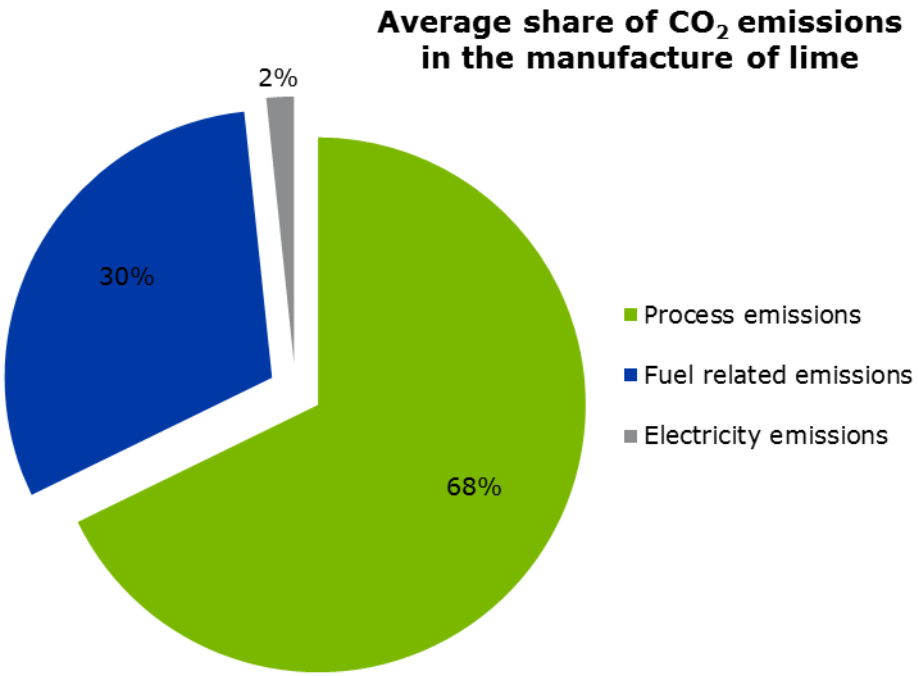

Figure 12: Average share of various sources for CO_2 emissions in the manufacture of lime for 2010 (EuLA, 2012)[48].

The specific CO_2 intensities are summarized in Table 7.

Table 7: Average CO_2 intensities for various lime products (based on data for 2010 (EuLA, 2012)).

Lime product	Process emissions (tonne CO_2 per tonne lime product)	Combustion emissions (tonne CO_2 per tonne lime product)	Electricity emissions (tonne CO_2 per tonne lime product)	Total emissions (tonne CO_2 per tonne lime product)
Quicklime	0.751	0.322	0.019	1.092
Dolime	0.807	0.475		1.301
Sintered dolime	0.913	0.635		1.567

The total direct CO_2 emissions – from EUTL, the EU-ETS emissions registry[49] – are around 26 Mtonne CO_2[50].

The next paragraphs will elaborate on methods and potential for reducing the CO_2 emissions of lime production.

[48] The shares of the different emission sources have been determined based on information from the EuLA Environmental Report 2012 (process and fuel emissions) and the electricity consumption described in paragraph 5.1.1.2. Electricity related emissions have not been obtained from (EuLA, 2012), but have been determined based on the assumption of 60 kWh electricity per tonne lime (refer to paragraph 5.1.1.2) and an average EU emission factor for electricity of 310 grams of CO_2 per kWh (obtained from (EU, 2011b)). It is important to note that this emission factor has been chosen to stay in line with the EU Energy Roadmap; the emission factor for electricity used in earlier carbon leakage assessments is considerably higher.

[49] A sector specialist has checked these by order of EuLA. Emissions related to purchased electricity are not included in this number. Number relates to quicklime, hydrated quicklime, dolime and sintered dolime, and non captive lime only.

[50] A few – small – lime installations are not covered by the EU Emissions Trading System and would therefore not be included in this number.

5.2 Abatement options

This chapter contains an overview of the most important CO_2 mitigation measures in the lime production process. The measures have been divided in three categories: energy efficiency measures, lower-carbon energy sources and end of pipe solutions (CCS, CCU and carbonation). For each measure the savings potential, applicability, development stage and barriers to deployment are discussed.

5.2.1 Energy efficiency

Stricter environmental regulations might in the future lead to additional energy use[51]; this has not been taken into account in this Roadmap.

5.2.1.1 Fuel savings

The average fuel use to produce quicklime is 4.25 GJ/tonne, while the heat of reaction – for a typical quicklime quality – is 3.03 GJ/tonne (refer to paragraph 5.1.1.1), 71% of the average fuel use. Theoretically, the potential for energy efficiency improvement for quicklime is therefore limited to 29%[52]; the rest of the fuel is simply needed to provide the *energy used in the reaction*. This is *a theoretical potential*, as in reality a driving force is always required to get the reaction going. It is to be regarded as the "impossible to achieve upper limit of energy savings potential". The potential for fuel savings is shown in Figure 13.

[51] For example: CCS (refer to paragraph 5.2.3) reduces CO_2 emissions, but at the expense of additional energy use.

[52] This number is applicable to the quality of quicklime described in paragraph 5.1.1.1, for other qualities the number would be different.

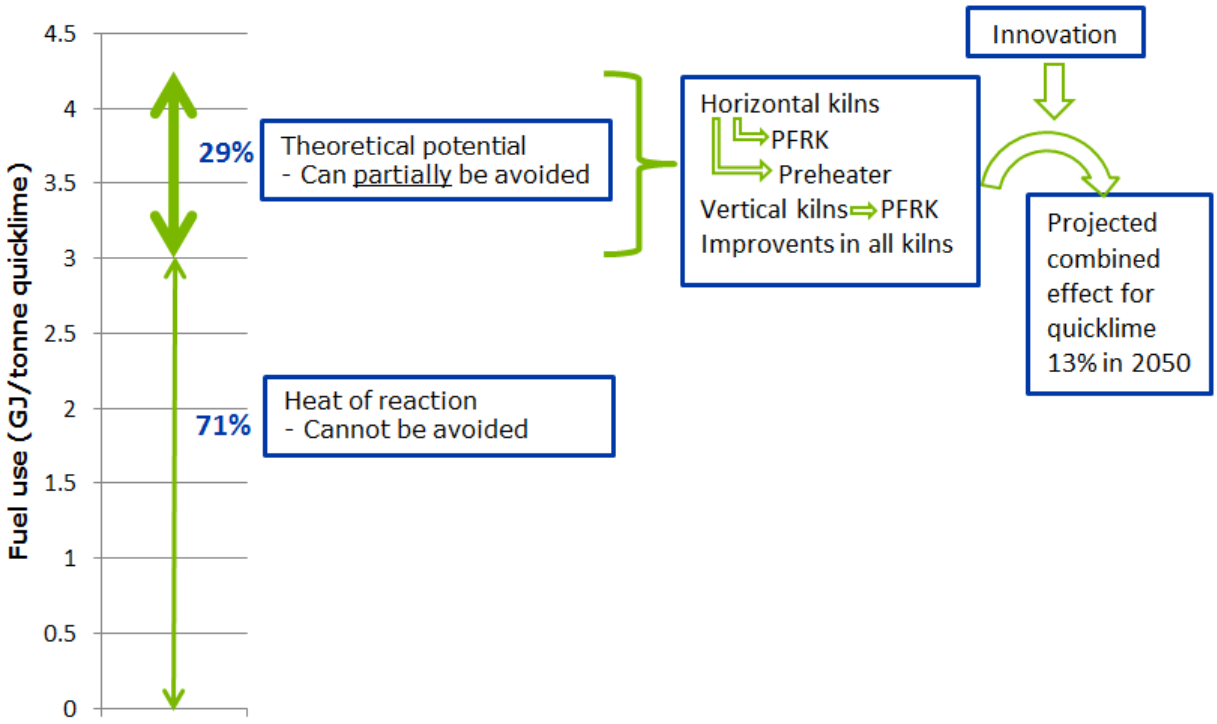

Figure 13: Theoretical reduction potential of fuel use and projected combined effect in 2050 for quicklime[53].

The options shown in Figure 13 are discussed in the next subparagraphs. Many of them are already available, but full applicability to all limestone particle sizes and lime products may well require innovation – as shown in Figure 13. Assuming this innovation will indeed take place, the fuel intensity for quicklime could decrease in 2050 with 13% (represented in Figure 13 as the projected combined effect)[54]. We assume the new fuel intensity would be achieved in 2050 – mainly by the building of new – highly efficient – kilns, partly by retrofitting currently existing kilns still in operation in 2050[55]. In 2030, the total decrease of the fuel intensity based on these assumptions is 7%.

[53] Theoretical potential of 29% relates to quicklime. The projected combined effect of 13% is determined on the basis of the distribution of the fuel use over the different kiln types for quicklime, with savings based on the fuel use when producing quicklime in the different kiln types, and is therefore applicable to quicklime.

[54] For lime products (including dolime and sintered dolime), a combined effect of 16% is projected. The theoretical potential is bigger as well. To arrive at the mentioned 16%, the distribution of the fuel use over different kiln types for lime products is taken into account, with savings based on the fuel use when producing quicklime in the different kiln types. The inaccuracy introduced by this approach is believed to be relatively small.

[55] With the average lifetime of kilns, the majority of currently operating kilns will already be taken out of operation in 2050.

Kiln Switch: Horizontal kilns → PFRK's

Figure 10 shows the energy efficiency of lime production increases when switching from horizontal kilns to vertical kilns. Parallel flow regenerative (vertical) kilns are the most efficient ones, but they cannot produce all products, and cannot process the smallest particles. The particle size is to a large extent determined by the crushing – prior to the kiln – although some limestone deposits only produce very small particles (chalk limestone). Currently, in Europe, 80% of lime is produced in vertical kilns (EuLA, 2013a)[56]. The share of rotating kilns decreases gradually due to the energy costs and the obligation to reduce emissions (CBPC, 2012). Some existing horizontal kilns have been refurbished in the EU, but they cannot achieve the same energy efficiency as a new vertical kiln.

The extent of switching from rotary kilns to PFRK's is determined by:

- The smallest particles can only be processed by rotary kilns; this can lead to a trade-off between resource-efficiency and energy-efficiency;
- There are also limitations in the ratio between the smallest particle and the biggest particle that can be processed by a kiln;
- The kiln type considerably influences the properties of the lime product produced[57];
- Different types of kilns have different capacities (horizontal kilns having the higher throughputs);
- Operational costs for kilns;
- Different types of kilns can produce lime products with different.

Further innovation could increase the applicability of PFRK's. At some production locations with multiple kilns, the bigger particles are processed in vertical – energy efficient – kilns, while the smaller particles are processed in horizontal kilns.

Kiln switch: LRK → PRK:

In horizontal kilns heat exchangers can be used to recover some of the heat from the flue gases exiting the kilns. This heat can be used to preheat the feed limestone. Vertical kilns already have a preheater zone.

[56] (CBPC, 2012) states: At the European level, 80-90% of the lime is produced in vertical kilns.

[57] Quicklime with a low reactivity is not generally produced in a PFRK (although innovations widen the applicability of the PFRK and the market share of low reactivity quicklime is decreasing); as "process conditions can be easily and quickly varied, long rotary kilns can produce a wider range of lime reactivity and lower residual CO_2 levels than shaft kilns" (JRC, 2013 (BREF)).

Text Box 10: From LRK to PRK: Installing a preheater

In 2008, a German lime producer transformed their long rotary kiln (LRK) into a shaft pre-heater rotary kiln (PRK). This has reduced the energy intensity by 23% and the CO_2 intensity by 13%. At the same time, the production rate has been increased by 25% and the limestone to lime ratio has been decreased by 4%. Figure 14 shows how part of the rotary kiln is removed during the installation of the preheater.

Figure 14: Removing excess kiln length during the installation of a preheater in a rotary kiln.

Kiln switch: Other vertical kilns → PFRK:

There seem to be not too many differences in applicability and product portfolio between the vertical kilns. The PFRK's are currently the most efficient vertical kilns and their share in verticals kilns might well increase in the future.

Other Fuel Efficiency Measures:

Apart from the switches in kiln type, several other measures to increase the fuel efficiency are available or could increasingly become available by innovation:

Improved use of Waste Heat:
The efficiency and CO_2 performance of the lime production process as a whole can be improved by using waste heat from the kiln in a useful way. The amount and temperature of the waste heat which is produced in the lime production process differs according to the type of lime kiln. Table 5 shows that horizontal kilns have the highest fuel use, and therefore, in principle, one would expect highest amounts of waste heat from these types. The waste heat can be used to dry limestone[58] or in the milling of limestone (EuLA, 2013a). In addition, the waste heat can be used in other industrial processes in other sectors with a heat demand, such as in the food and drink, pulp and paper and chemical industry (Norman, 2013). This does, however, require the proximity of suitable industrial partners, and existing plants usually already optimized their heat supply[59]. In addition, transporting waste heat can be costly. In order to make the collaboration between industrial partners possible, guaranteeing a security of supply is essential. These contractual obligations can form another deterrent in the useful application of waste heat (expert opinion).

[58] Which is done in a limited share of the lime plants (EuLA, 2013a).
[59] For example with CHP.

Alternatively, the waste heat could be delivered to buildings/residential areas – if available at limited distance. As an alternative, the waste heat can be used to generate electricity. An Organic Rankine Cycle (ORC) turbine can convert heat temperatures into electricity. A higher temperature leads to a higher efficiency. Other factors which influence the attractiveness of ORC turbines are installation costs, electricity costs and the current electricity provider/production system.

Text Box 11: 25% Electrical Efficiency Improvement: The First UK Organic Rankine Cycle

In 2013, the first UK Organic Rankine Cycle was installed on the site of a UK dolime producer. This ORC converts waste heat, captured with a self-cleaning heat exchanger, into electricity. This self-generated power increases the site's electrical efficiency by 25%.

Text Box 12: Lime Plant Warms Scandinavian Towns: Waste Heat from Kiln for Domestic District Heating

Several lime plants with a rotary kiln in Scandinavia provide warm water to towns for domestic district heating. This has reduced fuel consumption for domestic heating in the towns, which has led to reduced CO_2 emissions. The specific energy consumption of a plant and the production costs drop by selling the warm water, possibly at the expense of pre-heating.

Energy recovery in hydration:
The production of hydrated lime and dolime from quicklime or dolime is an exothermal reaction which generates heat. Hydrated lime accounted for about 18% of total sales in tons in 2012 (EuLA, 2013b). The heat produced during the production of hydrated lime amounts to about 1.2 GJ per tonne CaO and becomes available at a temperature of around 100°C (EuLA, 2013a). This heat could for example be used in industrial processes in for example the food and drink industry and the pulp and paper industry or for heating in the built environment (Norman, 2013); for many of the existing lime kilns this option is not straightforward, because the majority of lime kilns is located in rural or remote areas without any industry around it.

Other measures:

- Efficient insulation lining to minimize the shell heat losses: In general, vertical kilns are better insulated than rotary kilns (simpler insulation, because they do not move). Current heat losses through the kiln wall are ≥5%;
- Optimal Combustion process: This includes gravimetric fossil solid fuel feed systems and limiting excess air, ensuring burners deliver the required temperature;
- Improved process and input control: This enables to operate the kiln stably, closest possible to its specification, thereby increasing capacity, reducing emissions, improving quality, and preventing unnecessary energy use (-4% fuel utilization due to operation close to the stoichiometric minimum) (EuLA, 2013a);
- Optimal change-over management: This ensures lowest energy use in the transition phase during product changes;

- Optimal Maintenance: Prevents ingress of air by having air tight kilns and preventing erosion of refractory.

The sector sees no developments for application of Combined Heat and Power in lime kilns; this would require development of kiln concepts that are new for the lime industry.

5.2.1.2 Electricity savings

The focus of this Roadmap has not been on the identification of electricity saving options, given its limited impact the current electricity use has on the total carbon intensity of lime. The efficiency of motor systems is – conservatively - assumed to have a saving potential of 10% (UNIDO, 2011). Optimizing cooling could lead to a reduced consumption of cooling air. Optimizing grinding could lead to higher efficiency gains.

5.2.2 Lower carbon energy sources

5.2.2.1 Fuel switch

In this paragraph, the effects of switching to lower carbon energy sources are described, under the assumption that the shares of used fuels are not impacted by the energy efficiency measures described in paragraph 5.2.1. The current fuel mix has been shown in paragraph 5.1.2 in Figure 11. The CO_2 intensity of switching fuels decreases when fuels with lower emissions intensity would be used (in decreasing order: fossil solid fuels, waste, oil, gas, and biomass).

Although biomass has an emission factor of zero in this Roadmap, it is important to take the full life cycle GHG emissions of all forms of biomass into account in assessing the sustainability of biomass use[60]. Table 8 summarizes key factors for the choice between fossil solid fuels, gas and biomass.

Table 8: Key factors determining the fuel mix.

Factor:	Fossil solid fuels:	Gas:	Biomass:
Price of energy source	**Low - Moderate**	**High**	**Various**
Ease of use/ Maintenance	**Moderate**	**Easiest**	**Most handling (transport, drying, processing)**
CO_2 emissions	**Highest**	**Moderate**	**None (but: see above)**
Other emissions	**Highest (particles, sulphur)**	**Lowest**	**Moderate (Particles, other)**
Effect of carbon price	**Highest**	**Moderate**	**Not impacted**

[60] In this Roadmap, a scope 1 and scope 2 demarcation has been used (only emissions at the installations producing lime and the emissions associated with the generation of the used power are taken into account). That means that the emission factor for biomass is zero (no fossil CO_2 emitted). However, life cycle greenhouse gas emissions related to the production of biomass can be substantial and are the subject of intense debate in relation to the overall sustainability assessment of biomass use. Two sources of upstream greenhouse gas emissions can be distinguished:

- Direct greenhouse gas emissions caused by the production of biomass (farming, fertilizer production, transport and distribution, including change in land from high-carbon stock (e.g. forest) into low-carbon stock (e.g. agricultural land)), and
- Greenhouse gas emissions associated with indirect land-use changes (e.g. new forest to agricultural land conversion induced if existing cropland is used for bioenergy production).

The order of magnitude of these sources depends heavily on the type of biomass used and the regions and type of land where the biomass is cultivated.

Likewise, the upstream emissions for fossil energy sources are not taken into account.

Factor:	Fossil solid fuels:	Gas:	Biomass:
Required investment	**High**	**Low (piping + burners only)**	**Highest (adapt injection and burners, and pre-treatment) High maintenance costs**
Impact on quality		**Best**	
Availability	**High**	**High, not available for a couple of kilns due to their locations. Concerns over security of supply**	**Depending on other uses of biomass; sustainable sourcing important**
Applicability	**All**	**MSFK? All**	**Not for MSFK Apt for other types A wide variety of biomass can be used.**

Use of gas instead of solid fossil fuels:

Figure 11 shows that the current fuel mix contains 34% natural gas and 51% fossil solid fuels. Switching from fossil solid fuels use to natural gas would reduce the CO_2 intensity of lime production because gas has a lower emission factor than fossil solid fuels. There are some constraints for switching from fossil solid fuels to natural gas:

- High fuel costs for natural gas use;
- Concerns about access to natural gas and security of supply in the future[61];
- In the current situation, not all products can be made using gas, either due to economic or technical limitations;
- Not all lime plants are connected to the natural gas grid; connecting all would require considerable investments in the piping network – at least in the Nordic countries (EuLA, 2013a).

To quantify the effect, it has been assumed that the current 51% energy use in the form of solid fossil fuels would be replaced by gas and the average emission factor from the fuel mix before and after the fuel switch were compared[62]. This reduced the average emission factor of the fuel mix with 28%.

Use of waste as fuel:

As can be seen in Figure 11, waste currently accounts for 8% of the total energy content of fuels used in the lime production process. Different forms of waste can be applied. However, there are some constraints for switching to waste:

- The quality of waste fuels is important, since it affects the quality of the product (JRC, 2013 (BREF)). This quality should be constant;
- Not all types of kiln can process all types of waste:
    - Pulverised waste: All kilns except MSFK's;
    - Solid-lumps waste: All kilns except PFRK and some 'Other Kilns';
    - Liquid waste: All kilns;

[61] Lack of availability of gas could lead to loss of competitiveness.

[62] Emission factors of 56.1 (tonne CO_2/TJ) for gas, 74.9 (tonne CO_2/TJ) for liquid, 100.0 (tonne CO_2/TJ) for fossil solid fuels and 82.5 (tonneCO_2/TJ) for waste (EuLA, 2010). For waste: The current composition of the waste used, and therefore its emission factor, is unknown to EuLA. Therefore, the emission factor for waste has been determined by assuming that 50% of the waste is liquid waste and 50% of waste is solid waste. The emission factor of the liquid waste is 73.3 tonneCO_2 per TJ and the emission factor of solid waste is 91.7 tonneCO_2 per TJ (EuLA, 2010). This results in an emission factor of 82.5 tonneCO_2 per TJ. For the emission factor or liquids, and likewise for the emission factor of solid fuels, equal shares of the different forms have been assumed.

- Legislation might play a role in the application of waste, since different legal requirements exist for different Member States (EuLA, 2013a).

The applicability of waste fuels might be increased by innovations such as Ecoloop (paragraph 2.3).

Use of solid biomass as fuel:

Different forms of biomass can be used. Introducing biomass in the different kiln types requires attention because:

- Especially in shaft kilns, combustion of fuels occurs in the material bed and interaction with the material bed can be a bottleneck;
- Biomass materials can have appropriate combustion kinetics, but cause kiln blockages;
- Biomass particles need to be small (2-3 mm) in vertical kilns; in rotary kilns, larger particles are possible (1-2 cm);
- Maintenance for biomass tends to be high (EuLA, 2013a).

Therefore, research is on-going to improve the applicability of biomass, especially in PFRK's. Currently, some 14 PFRK's, 2 (captive) rotary kilns and one projected (captive) rotary kiln are known to be reengineered or newly built where finely ground wood is used. Two more kilns are fuelled with cork. Research targets olive stones; coconut cores, sugar cane, jatropha nuts and rice hull for use as biomass fuel. In Brazil, there are many PFRK's, amongst the best performing ones that can operate on biomass.

Text Box 13: Biomass in PFRK's

A Belgian Company invested in a wood mill for chips, and a storage facility adapted to fine wood particles. Overcoming the challenge of the variability of the quality, humidity and fineness of the waste wood supply, it is now received, milled, stored and used in PFRKs. The project yielded the capacity to use more than 30% waste wood in a PFRK.

Use of gaseous biomass as fuel:

Biomass can be converted to syngas, and then used to heat kilns. The Ecoloop process could help (refer to paragraph 2.2).

PFR kilns are usually designed to combust natural gas with a calorific value of 48 MJ/Nm^3, but they can also run on coke oven gas (16-35 MJ/Nm^3). Now, research is being conducted on running these kilns on much leaner gas types (<7.5 MJ per Nm^3)[63]. Actually outside Europe, some kilns are already operated on converter gas or blast furnace gas (Schlegel, 2013), but could in future also be operated on biogas, sewages gas or landfill gas (EuLA, 2013a).

[63] Using leaner gases requires a larger kiln to maintain the same capacity; a larger kiln could have higher heat losses through the kiln wall (EuLA, 2013a). R&D will need to show the lower limit for the caloric value of the used gases.

The text box below shows the required area for supplying the total fuel for lime products manufacture by biomass[64].

Text Box 14: All Fuel Supplied by Biomass

In case all fuel needed for EU non captive lime production by EuLA members would be supplied by biomass, an order of magnitude calculation shows that the amount of land needed to produce this biomass would be between 800 km^2 and 21.000 km^2. For Europe, this rough order of magnitude area would be 6.000 km^2 [64].

Use of electricity to heat kilns:

Electricity might be used to heat kilns. With the decarbonisation of power generation as foreseen in the EC's Energy Roadmap (European Commission, 2011b) this would be low carbon heat production. However, with current and foreseen power prices this option is not economically attractive. The situation is different in times of oversupply of electricity, resulting in cheap/free electricity. Using electricity to heat the kilns might be feasible then and could help to bring supply and demand in equilibrium. This option requires extensive R&D.

Solar heat:

For solar thermal technologies to provide the heat needed in the calcination process, the heat quality should be at least 900°C. In the future, high-temperature Central Receiver Systems (CRS) with pressurised air could reach temperatures up to 1000 °C. A prototype receiver demonstrated a receiver temperature up to 1000 °C (DLR, 2005). Due to differences in the composition of the atmosphere and the weather, good irradiation circumstances for CRS are usually found in arid and semi-arid areas with reliably clear skies (typically at latitudes between 15° to 40°, North or South) (IEA, 2010). Thus the most southern parts of Spain and Italy, as well as Greece and Turkey could become viable locations for solar-powered lime production.

Potential:

Due to the high uncertainty and complexity, the realistic abatement potential from fuel switch has not been established. In paragraph 5.3 the effect of two hypothetical assumptions is shown though.

[64] These are both order of magnitude calculations, using the production figures mentioned in paragraph 4.1, and assuming a biomass production of 50-1350 GJ/ha/year (for USA wood and above-ground sugarcane Zambia (Larson, 2008)). Currently, the biomass used by the EU lime industry is mainly residue biomass, to which no land area can be attributed. For biomass specifically planted for energy purposes, the yield (GJ/ha) varies extremely over different regions and different types of biomass. For Europe, the area is based on willow (180 GJ/ha/yr) (EuLA, 2013a).

5.2.2.2 Greening of electricity emission factor

As can be seen in Figure 12, emissions from electricity consumption during lime production are small (2%) compared to other emissions. In paragraph 5.2.1.2 it has been indicated that the efficiency of electricity consumption can improve somewhat. The CO_2 emissions related to the use of electricity will, however, decrease much more significantly by the decarbonisation of the power generation. The EU Energy Roadmap (EU, 2011b) projects[65] a decrease of the carbon intensity of power generation of 42% (2030) and 71% (2050). In other words: Even without action from the EU lime industry – but also outside its span of control – the CO_2 emissions associated with its electricity use will drastically decrease.

5.2.3 End of pipe solution: Carbon Capture and Storage/Utilization

CCS:

The earlier paragraphs showed that the energy related greenhouse gas emissions can be reduced to some extent. However, the process related emissions – already now forming the major share of the emissions (refer to Figure 12) – are not impacted by any of these options. To reduce these, within the current processes, the CO_2 released in the process has to be captured, and dealt with afterwards[66]. TNO has made a techno-economical evaluation[67] for EuLA of post combustion CO_2 capture in lime production plants (TNO, 2012). For the state-of-the-art solvent (MEA) costs to capture CO_2 were €94 per tonne of avoided CO_2 (refer to paragraph 5.2.5 for more information). The cost to capture CO_2 would more than double the production costs of around €60/tonne lime (described in paragraph 4.2). In case waste heat can be used for solvent regeneration, these costs would be reduced. Innovations provide the potential to reduce the cost associated with capturing CO_2; quick uptake accelerates innovation.

Currently, lime plants are typically located right next to the deposit, not clustered in large industrial agglomerations. Transport costs – to overcome the distance between the lime plant where CO_2 is captured and the location where it is stored or used - can add significantly to the capture costs, especially since CO_2 emissions from lime plants are relatively small (in comparison with major industrial sites/power plants), and for lime plants at distant locations without nearby presence of existing CO_2 transport infrastructure to connect with. Appropriate planning of CO_2 transport infrastructure leading to the availability of a transport infrastructure to tie in to could reduce CCS costs for the sector.

Storage locations need to be developed and maintained as well.

At present costs for capturing the CO_2 emitted by a lime plant do not lead to a feasible business case. In future, changed policies such as carbon pricing with high carbon prices or obligations could increase the economic attractiveness of CCS. Should CCS become feasible in the future, it is questionable whether lime kilns would be the most logical first choice for CO_2 capture (other industrial processes may generate more pure and more concentrated CO_2 without any additional processing steps).

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[65] For the Current Policy Initiatives scenario.

[66] Theoretically, one could also consider to produce lime products with a lower percentage of lime (thereby reducing the generation and emission of CO_2 during the production of the lime product) – and more limestone. However, the client would then either need more lime product for the same CaO functionality, or generate the CO_2 saved in the production of lime product when using it (EuLA, 2013a). This solution would therefore not provide an advantage.

[67] This analysis included the direct contact cooler, absorber, heat exchanger, stripper and compression section. The CO_2 removal from the flue gas was set at 90% and the final CO_2 pressure was set to 110 bar. The specific heat consumption for the AMP/PZ solvent is around 3.1 GJ/tonneCO_2 captured (the heat is assumed to be generated in a gas-fired boiler). Electricity consumption of 129 kWh/tonne CO_2 is required to power the fans and pumps and the compressor cost for the AMP/PZ system (TNO, 2012).

Next to cost issues, currently, implementation of CCS in the EU faces other barriers:

- Public acceptance for local CCS projects seems to be low ("not in my backyard");
- Legal issues regarding liability.

Uptake of CCS depends on all the factors above, and the impetus.

Text Box 15: Alternative technologies for CO_2 Capture: Oxy-firing and Capture Using Limestone

Apart from the capturing technique described in the main text, an alternative technology, oxy-firing, is developed. With oxy-firing, oxygen is used instead of conventional air for combustion in the lime production process. As this eliminates the diluting N_2 introduced with the use of air, this facilitates the concentration of CO_2 from the flue gasses, at the expense of additional energy use to produce the oxygen. However, (TNO, 2012) mentions that:

- Issues with air leakage and effects on lime quality need further research;
- The use of oxygen increases the temperature of the kiln, which causes sintering (TNO, 2012).

The conventional way of cooling the process by bringing relatively cool flue gasses back into the process could be possible in lime kilns, but needs far more engineering and process control, as contact between the recycled CO_2 rich flue gas and the lime leads to immediate carbonation, diluting the lime quality (EuLA, 2013a).

CO_2 can also be captured from flue gases using limestone – or other materials - with a wet scrubber installation. Limestone in combination with CO_2 and water forms calcium-hydrogen-carbonate, which can be released in rivers, lakes and oceans. This has the added benefit eliminating the problem of CO_2 storage and functioning as an acidity buffer in oceans. Research on this technology is on-going.

Text Box 16: Carbonate Looping – Lime Use in CO_2 Capture

Lime can be used to capture CO_2 and release it again at a different temperature range. In a first step, the CO_2 is captured by lime in a carbonator at 650°C. In a next step, it is calcined at 900°C to release the CO_2. Carbonate Looping claims to have a lower energy use than other capture technologies, which can lead to reduced costs for Carbon Capture and Storage (CCS). Lime companies are participating in pilot tests for this capture method (EuLA, 2013a).

Text Box 17: Participation in CCS Research

Together with several other industrial and energy companies, a lime manufacturing company is contributing to CCS research by contributing to the financing of Bastor2. The Bastor2 project (Baltic Storage of CO_2) conducts research on the geological aspects, environmental and societal impacts, legal and fiscal aspects and infrastructure and transport of CCS (EuLA, 2013a).

CCU:

The business case for CCS – as described in the previous paragraph – could be improved in case the captured CO_2 could actually be used, rather than stored. Storage costs could be saved, and the CO_2 might get a positive value. The lime industry itself will not be an industry using the CO_2, but its business case to capture the CO_2 could benefit from others using CO_2. A lot of research is currently devoted to developing new uses of CO_2, such as:

- CO_2 could be used to **produce fuels/hydrocarbons**. This would require significant amounts of energy (the combustion process needs to be reversed – so the energy released during the combustion process now needs to be inserted); when the aim is to reduce CO_2 emissions, this energy should be produced carbon free; a prerequisite for building new hydrocarbon structures from CO_2 is thus the availability of cheap excess carbon-free energy or waste heat (in presence of an apt catalyst); the use for CCU competes with other uses for this competitive carbon-free energy. Micro algae could be used to convert CO_2 in these fuels/hydrocarbons.
- CO_2 can convert minerals into inert carbonates, to be used for example as **construction material**.
- CO_2 can also be used as a feedstock for products actually **benefiting from (variations of) the O=C=O structure**, such as polymers such as polyols (CEFIC, 2013).
- CO_2 can also be used to **enhance recovery of fossils** (oil, gas).

Many of these applications require significant innovation before becoming technically proven and/or economically attractive.

Text Box 18: Biofuel Production from CO_2 Emissions from Lime Production

A lime producer partnered in the Agical+ research project (financed under the European Commission LIFE+) that aimed at making use of the lime and glass sectors CO_2 emissions. This project looked into an innovative solution, based on algae culture and biomass production, which would allow for the CO_2 capture of lime or glass furnace fumes and the production of biofuel that could be used within the furnaces during the production process. If applied at full-scale, such technology might significantly reduce CO_2 emissions and consumption of fossil fuels related to lime and glass production industries. However the economic analysis done in the project revealed that the cost of the biofuel produced would be around €650/GJ, or around a 100-fold more expensive than traditional energy resources (natural gas, heavy fuel).

CCS/CCU is the abatement measure with the biggest abatement potential of all, and in fact the only one tackling process emissions during manufacture of lime products. Its costs are high in comparison with the production costs of lime. Given the right technological development, economic situation and infrastructural requirements and with an incentive not harming the EU lime industries competitive position, the EU lime industry embraces this technology. Therefore, as is shown in the Textbox above, the lime industries are already contributing to its further development.

5.2.4 Carbonation (natural)

The mechanism described in this paragraph is not a "traditional abatement measure" that the lime industry could take, but rather an effect associated with the use of lime, to be taken into account when assessing the emissions during the manufacturing of lime products.

During the lifetime of products in which lime is applied, CO_2 from the atmosphere is captured (basically reversing the reaction in which lime is produced from limestone). More specifically, direct carbonation of quicklime is not observed at ambient temperatures, but carbonation can take place after a hydration step ("slaking" in the industry, or by atmospheric wetting). Atmospheric CO_2 has good access to for example building materials and can undergo reactions to some extent with the lime itself or its derived compounds, ending up again in the formation of $CaCO_3$. This so-called "carbonation" partly closes the cycle starting with CO_2 process emissions during lime production. This mechanism is summarized in Figure 15.

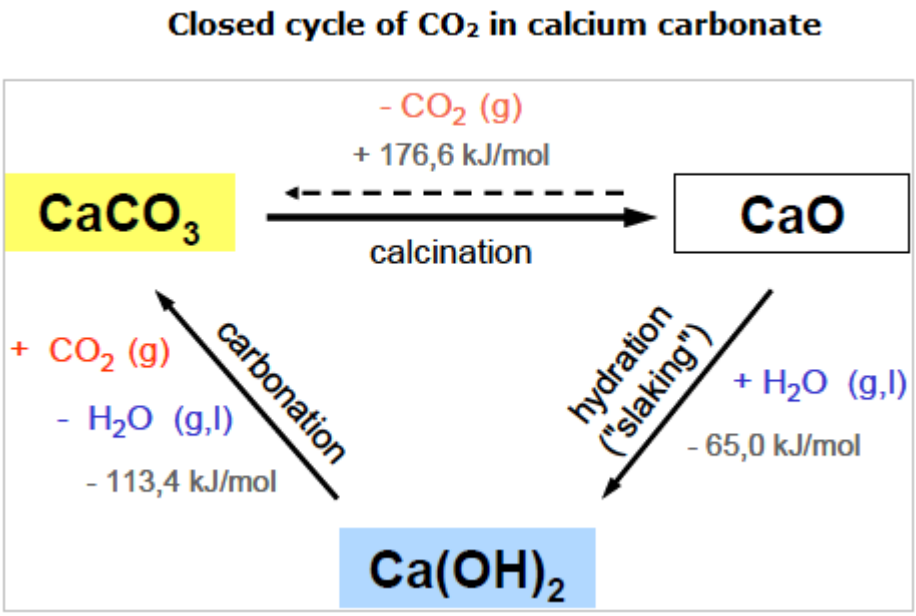

Figure 15: Closed cycle of CO_2 in calcium carbonate (TU Clausthal, 2008).

Of course, the rate of carbonation and its permanence are important parameters in assessing the environmental benefits from this mechanism. It is highly dependent on the application: in some applications the main carbonation takes place within five years, in other applications it takes longer.

For mortars (EESAC, 2013) indicates – based on a literature study - that within 100 years, 80-92% carbonation takes place[68]. As ±4% of lime is used in mortar and process emissions currently form 67% of total emissions associated with the manufacture of lime (Figure 9), the carbonation amounts to ±2% of the emissions stemming from EU lime production.

For other applications, this has not yet been investigated with similar granularity; the lime industry is keen to continue these investigations, and to discuss impacts of the findings with other stakeholders. Then, methodologies for possible inclusion of the findings in for example LCA's and policy making can also be discussed.

Precipitated Calcium Carbonate (PCC) – a high purity lime product obtained by reacting from lime with CO_2 – is an industrial example of the same mechanism.

[68] With the assumption that the mortar is still in use after 100 years.

5.2.5 Costs associated with abatement measures

Text Box 19: Availability and Costs for Abatement Measures

All abatement measures mentioned in the next paragraphs are commercially available. Some limitations exist on the applicability of certain measures in certain situations, which have been discussed in detail in their respective sections. However, further innovation and technological progress could remediate some of these limitations over the following decades.

In spite of the commercial availability of the measures, wide scale implementation is currently inhibited by high investment costs of some of the measures, leading to high payback periods. In the next decades innovations, increasing energy- and CO_2-prices and investment support schemes might make these measures more financially attractive.

The numbers in the table below give an impression of the investment costs associated with the uptake of the measures.

Table 9: Overview of abatement costs for key measures taken into account in this Roadmap.

Measure:	Abatement costs (€/tonne CO_2):	Investment costs:	Savings (%)[69]:
Energy efficiency:			
Rotary kilns → Shaft kilns	45	€100/tpy	45%[70]
LRK → PRK	38	€72.5/tpy	30%[71]
All shaft kilns → PFRK	331	€100/tpy	19%[72]
Continuous improvements[73]	Varies	Not assessed	3-7%[74]
Fuel Switch:			
All solid fossil fuels → Natural gas	91	No investment[75]	28%[76]
All → Biomass	43	10.9 €/GJ	100%[77]
CCS (Capture)	94	€76/ton CO_2 avoided	70%[78]

This table has been prepared by EuLA members; where possible its starting points are aligned with the starting points for this Roadmap document. It is a simplified assessment, based on investment costs and changes to the fuel costs only. More information on the underlying assumptions can be found in the

[69] Savings relate to a different scope for the different lines in this table, so savings cannot be added or be directly compared with each other.
[70] Related to the combustion related emissions of all rotary kilns.
[71] Related to the combustion related emissions of the modified kilns only.
[72] Related to the combustion related emissions of the modified kilns only.
[73] Combined effect of installing new kilns and optimizing existing kilns.
[74] Related to the combustion related emissions of the modified kilns only.
[75] Assuming natural gas is present at the site.
[76] Related to the combustion related emissions only.
[77] Related to the combustion related emissions only; in reality 2% of natural gas would be required for start-up purposes.
[78] The TNO report (TNO, 2012) assumes 90% of CO_2 is captured; obviously other efficiencies could be attained as well, at different costs. We arrive at 70% by accounting for avoided CO_2 emissions – and assuming complete decarbonisation of power (somewhat more than assumed in the remainder of this chapter).

annex. For all the reasons mentioned in the annex, these numbers should be further investigated before using them as a basis for policy making.

5.3 Pathway to 2050

As stated in paragraph 1.3, this Roadmap in its current version is focusing on energy and carbon pathways towards 2050.

Figure 16 shows a breakdown of the current direct CO_2 intensity of lime production relative to 2010 and a projection for the direct CO_2 intensity in 2030 and 2050:

- Around two thirds of the current direct emissions are process emissions, indicated in green;
- 31% of the emissions are related to the use of fossil fuels, indicated in blue;

The **fuel intensity decreases** in 2030 and 2050 due to energy efficiency improvements (refer to paragraph 5.2.1) – shown in striped blue. The effect on total emissions is rather limited, because:

- The improvement potential for energy efficiency in the PFRK's is limited because the (best-in-class) kilns are already operated not too far from the heat of reaction (Figure 10);
- Fuel related emissions currently only account for 31% of the total emissions (Figure 12).

Apart from the above, most of the potential to decrease the fuel intensity comes at CO_2 abatement costs of mostly ≥ €38/tonne, in case the investment would be driven only by the decrease the fuel intensity.

The remaining emissions in 2030 and 2050 can be reduced by **switching to lower carbon fuels** or by **capturing/utilizing CO_2.** <u>The technical potential of these options is shown by arrows with a colour gradient, representing the huge uncertainty in the potential that could be realized in 2030 and 2050. It should be kept in mind that this technical potential is intended as a thought experiment, not to reflect a possible reality/economical potential.</u>

The figure shows two options for switching to lower carbon fuels:

- A fuel switch from **fossil solid fuels to gas** in 2030 and 2050;
- A **full decarbonisation of the fuel mix**, for example by using biomass[79] (in 2050).

These options are shown as the yellow arrows in Figure 16. At current fuel prices, switching from solid fossil fuels to gas comes at significant CO_2 abatement costs and is not attractive unless quality requirements demand the use of natural gas; a lower natural gas price would reduce these abatement costs. Fuel switch to biomass comes at lower abatement costs – abatement costs are highly dependent of the local price of the locally available biomass; replacement of natural gas by green biomass can well be attractive.

The last (blue) arrow represents the technical potential of **Carbon Capture and Storage/Utilization**. This technique could bring deepest emission cuts. Again, it is important to understand the barriers related to CCS/CCU (refer to paragraph 5.2.3), especially related its significant costs.
In practice, it could be foreseen that in 2050 (some?) of the larger lime kilns/plants, not too far from appropriate storage locations, would be equipped with CCS/CCU.

When assessing the effect of the remaining carbon emissions, the mechanism of natural carbonisation (refer to paragraph 5.2.4) could be taken into consideration. The lime industry will continue to investigate

[79] Refer to paragraph 5.2.2.1 for a description of upstream emissions that are associated with the use of biomass.

these effects and methodologies to account for them. Their – unknown – effect is illustrated by the orange bar at the bottom of Figure 16.

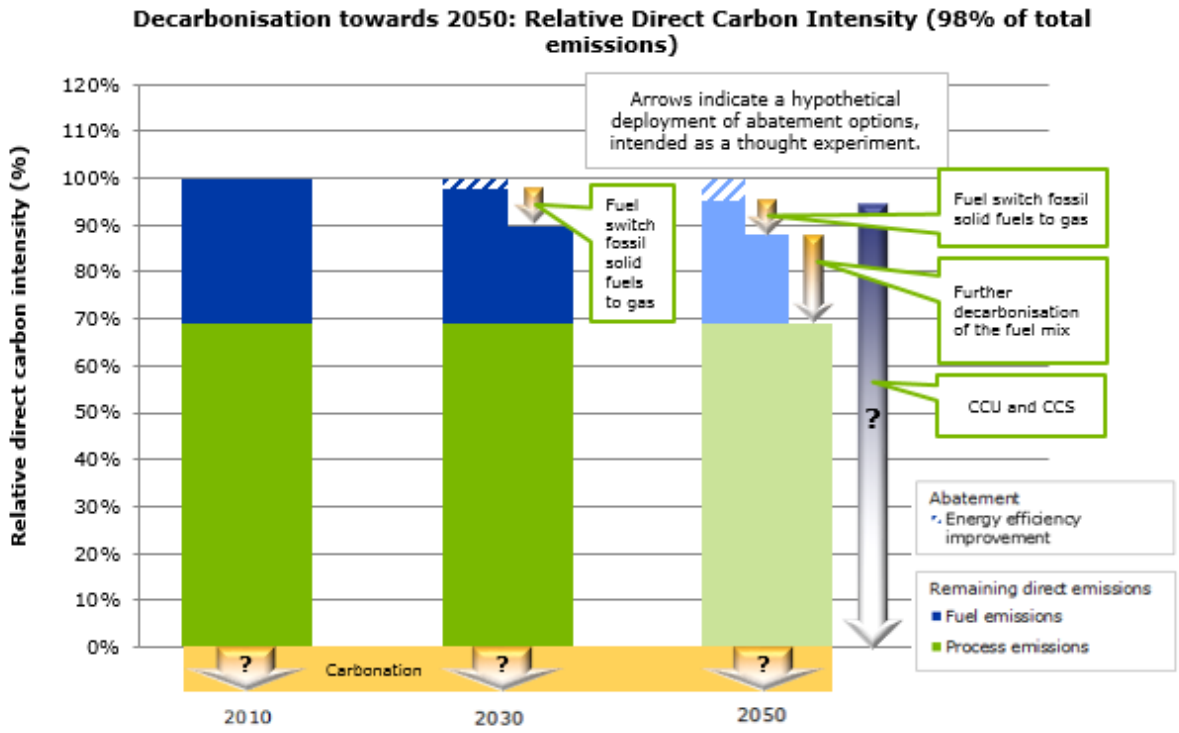

Figure 16: Possible development of the carbon intensities of lime production for 2030 and 2050, compared to 2010. Direct emissions only, which form about 98% of total emissions. The scope of these emissions is from factory gate to factory gate. Green bars reflect process emissions, blue bars reflect fuel emissions and the striped blue block indicates energy efficiency abatement. The orange bar reflects the – unknown – effect of natural carbonation. The arrows (apart from the arrows in the carbonation part) indicate the technical potential of emission reduction options[80]. Note that intensities do not include upstream emissions related to fuel production (mainly relevant for bio fuel; refer to paragraph 5.2.2.1).

Figure 17 shows the development of the relative indirect carbon intensity (from electricity), in comparison with the 2011 intensity. In 2011, indirect emissions were 2% of the total emissions, so this figure represents a very small share of the sectors total emissions. Nevertheless, the blue striped bar shows that some efficiency measures reduce the electricity intensity (refer to paragraph 5.2.1.2), and the striped orange bar shows the decreasing carbon intensity of the generation of power (outside the control of the European lime industry; refer to paragraph 5.2.2.2). The figure shows that the impact of the use of electricity is projected to significantly decrease the next decades.

[80] The effectiveness of CCS to reduce the CO_2 intensity could in practice be limited by unavoided CO_2 emissions resulting from the generation of power and heat, and by the incomplete capture rate of CO_2. This is one of the reasons for representing the arrow more vaguely in the downward direction, and for the question mark in the arrow.

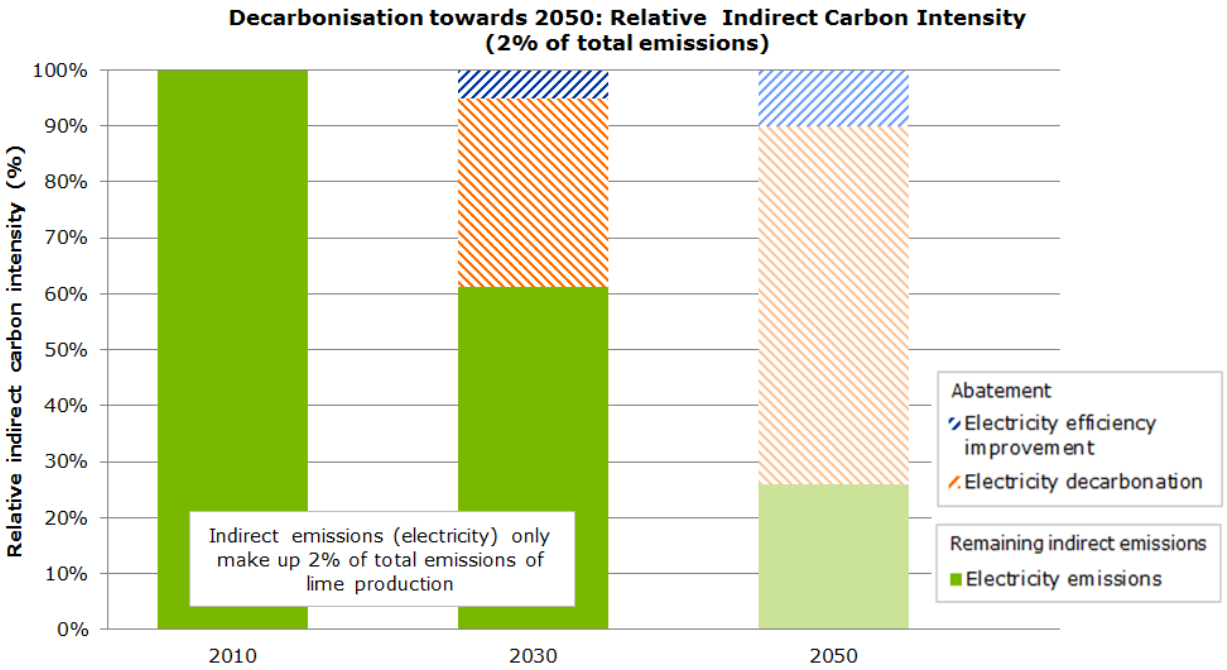

Figure 17: Course of possible future carbon intensities, indirect emissions (electricity), which make up about 2% of total emissions (carbon intensity relative to 2010 for lime production in 2010 and for the hypothetical situation in 2030 and 2050. The green bar reflects electricity emissions, the striped blue bar indicates electricity efficiency improvement abatement and the striped orange bar indicates electricity decarbonisation abatement.

6 Overview of Key Findings

This section provides a brief overview of the key findings from the previous chapters.

The European lime industry sector provides 11.000 direct jobs, and its products are applied in many different sectors and products. Lime is an important component of the value chain for energy intensive industries. The sector is relatively small, but very greenhouse gas intensive. Unilateral European climate policies can lead to high carbon prices for the lime sector as well as for other European industries. This can negatively impact the lime industry in Europe, while at the moment the relatively high energy prices in Europe already put the competitiveness of the European industry under pressure.

If the lime sector is not protected from the effects of unilateral EU climate policies, it can suffer from the following two effects:

- The European demand for lime will decrease, because the production prospects of the main lime consuming industry in Europe will be negatively impacted by high carbon prices;
- The competitiveness of the European lime industry itself will be negatively impacted by high carbon prices compared to outside EU production.

The lime sector could try to mitigate the effects of higher energy and carbon prices by reducing the energy and carbon intensity of its production process.

However, the options for the EU lime industry appear to be limited:

- Two thirds of the greenhouse gas emissions from the European lime industry are caused by raw material related process emissions (lime is produced by converting limestone into lime and CO_2). These process emissions can be reduced by capturing the released CO_2. Captured CO_2 can be stored underground (CCS), or used (CCU). Currently, due to the high cost of capturing and storing, it is not economically feasible for lime producers to apply these technologies.
- The remaining part of greenhouse gas emissions can also be reduced by either increasing the energy efficiency of the production process, changing towards lower carbon fuels, or by reducing the greenhouse gas emissions associated with electricity use.
- The potential for these three options are illustrated below:
    - For **energy efficiency**, it is projected that around halve of the theoretical potential for energy efficiency improvements could be captured. In this Roadmap, energy efficiency improvements for lime products of 16% are projected for 2050. The effect on the total emission intensity is around 4.9%.
    - The potential of **using lower carbon fuels** is at most 31%[81], deployment levels will depend on technical and economic considerations.
    - The emissions associated with the use of **electricity** will mainly decrease as a consequence of the decarbonisation of the European power production, as foreseen in the

[81] Ignoring upstream emissions in the production of biomass (and fossils) – as a consequence of the scope of this Roadmap (refer to paragraph 5.2.2.1) and in case of no energy efficiency improvements.

EU Energy Roadmap (European Commission, 2011b). The effect on the total emission intensity is around 2%.

Based on these figures, the lime industry has few options of reducing the costs of increasing energy and carbon prices by itself. For that reason, it asks for EU policy to play a role in this process. The following chapter will provide more details on this topic.

7 Policy Recommendations

The key findings from this Roadmap have been summarized in the previous chapter. This is the basis for EuLA's policy recommendations given below. These policy recommendations are – in line with their request to the sectors to make their own Roadmap - directed towards the European Commission to take into consideration when establishing policies, for example the 2030 energy and climate policy framework. For the European lime industry, it is crucial that the transition to a low carbon economy is achieved in a smart way.

Last year the European Commission re-launched the debate on EU industrial policy aiming to reach the target of 20% contribution of the industry to the European GDP by 2020. An effective EU climate- and industrial-policy should first of all be coherent with all existing EU policies, for example on competitiveness, climate change, energy, inclusive growth, anti-dumping, state-aid. Therefore, coordination between the different EC DGs relevant for industry, such as Environment, Internal market, Competition, Enterprise and Industry, Research, and Climate Action should be enhanced, as at the end all those initiatives and actions have a cumulative effect on each company.

7.1 Keep the whole value chain in the EU

Lime is a crucial and versatile everyday product, being used in many EU industrial sectors. The lime industry usually operates close to its clients. In that sense its competitiveness largely depends on the presence of its clients in Europe (for example the iron and steel industry). Further incentivizing a shift towards a low carbon economy may give new market opportunities, but at the same time the EU should safeguard that as many European companies as possible benefit and that production remains in the EU. A win-win should be found by providing the right impetus.

European climate policies adding a unilateral burden to the European manufacturing industries in combination with continued differences in energy prices would not impact the European demand for end products manufactured using lime, but would affect the European lime industry in the following ways:

- Reduce the competitiveness of the European lime sector's European clients thus reducing European demand for lime products;
- Increase the difference in lime production costs between Europe and surrounding countries, thereby increasing incentives to import lime to replace the EU production to meet the remaining lime demand.

This means the European lime industry would be impacted twice: Competitiveness of EU client sectors decreases, and competitiveness of EU lime producers decreases. This is summarized in Figure 18. Europe should therefore continue its efforts towards global rather than unilateral action against climate change, striving for a global level playing field for industry.

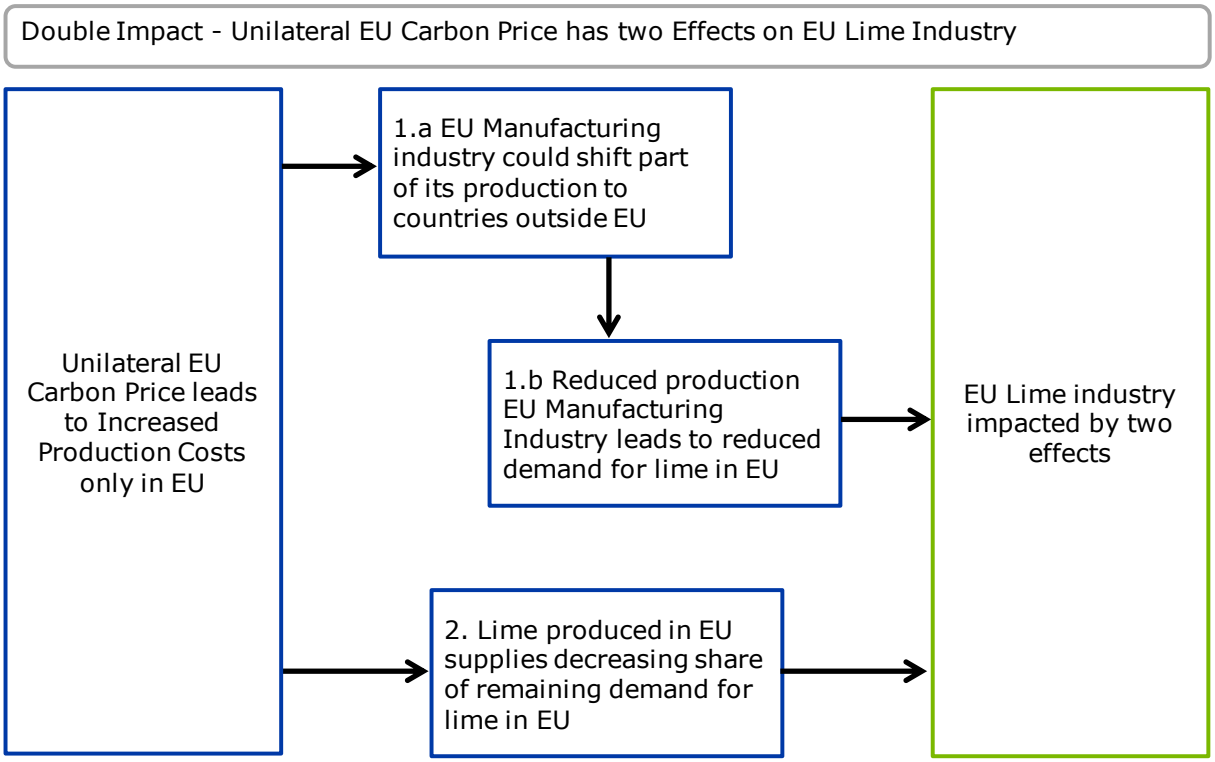

Figure 18: Double impact of unilateral EU carbon prices on the EU lime industry. A shift of lime consuming industries to non-EU countries reduces the EU demand for lime, and thereby reduces European lime production. Increasing import of lime could further reduce European lime production.

When the carbon efficiencies of the manufacturing facilities of the importers would be at par with those of EU producers, the global emissions would rise as a result of a unilateral carbon price in Europe, when measures would fail to prevent imports from third countries.

7.2 Competitiveness of EU lime production

Chapter 4 makes clear that energy and carbon prices have an enormous impact on the production costs for the lime industry: typically energy costs – excluding carbon costs - determine around 40% of total production costs. Variations and uncertainties in these prices – and in carbon costs - have a high impact on the business case of European lime production and future investment. Therefore, in order to enable European lime producers to take long term business decisions, a stable and predictable policy environment in Europe is required.

With energy costs determining such a large share of lime production costs, the differences in energy prices between EU and surrounding countries put the competitiveness of the EU lime industries under pressure. Like for any energy intensive industry, having access to energy at reasonable cost is an essential condition for operating in the EU. To alleviate the differences in energy prices, the European energy policy should:

- Include fully integrated and well-functioning electricity and natural gas markets;
- Consider to integrate energy requirements in international negotiations;
- Guarantee a diverse and more competitive energy supply in Europe (refer to paragraph 4.3);
- Eliminate differences of energy prices within Europe as a consequence of national differences in energy taxation.

Chapter 4 shows that, in case a global level playing field cannot be reached in climate negotiations, already at a limited unilateral carbon price in combination with differences in energy prices, neighbouring countries may be able to export into parts of the EU. Protection to prevent loss of competitiveness as a consequence of unilateral climate policies is therefore important for the European lime industry, for example by a cost levelling mechanism (such as compensation). It is therefore important that the European Commission pays sufficient attention to the risk of carbon leakage to neighbouring countries[82], and is aware that the relatively high energy prices in Europe already put the competitiveness of the European industry under pressure.

Compensation mechanisms should compensate the effects of unilateral EU climate policies fully for the best performing lime operators, also in times of production increases.

Depending on the definition of the GHG reduction targets for 2030 and on the outcome of the international climate negotiations, negative impacts of energy and climate policy on the competitive position of the European industry remains a concern after 2020. EuLA recommends including comparative energy costs in its assessment of the competitiveness of the EU manufacturing industries and relating costs of negative impacts to transport costs.

7.3 Emission reductions

As is shown in chapter 5.2, deep emission reductions can – as a consequence of the process emissions associated to the manufacture of lime – only be achieved by capturing the emitted CO_2. Smaller abatement contributions come from switching to lower carbon energy sources and from energy efficiency improvements. Innovation could help to accelerate the uptake of these abatement measures by:

- Reducing the costs for Carbon Capture and Storage (oxy-fuel, demonstration plants, etc.), and improving the feasibility of Carbon Capture and Use (many possibilities outside the lime sector, improving the business case for carbon capture);
- Improving the applicability of low carbon fuels, by removing technical bottlenecks;
- Improving the applicability of more energy efficient kilns (particle size, products).

The European Commission could stimulate these innovations by stimulating research while taking intellectual property rights into account, reducing barriers for subsidies, and by developing adequate financing systems for the early adoption of energy efficient and low carbon techniques.

[82] Not 'just' the big economies.

Further stimulation for the uptake of abatement measures could include:

- Stimulating the development and deployment of CCS to put the EU lime industry in a position to quickly take on CCS once conditions are right. Liability issues should not form a barrier. The European Commission may consider investigating the possibility of providing public infrastructure for transporting and storing CO_2.
- Accelerate the uptake of investments in abatement measures with development of innovative investment models to attract finance for measures that do not meet the industry financial thresholds, or other forms of support for low-carbon investments. These systems could be financed by using part of the revenues from ETS to provide cheaper loans for low carbon investments in installations falling under the EU ETS.

When the Commission sets targets for emission reductions, they should:

- Take differences between sectors into account:
    - Abatement potentials vary over sectors; for example, in the absence of – affordable – Carbon Capture and Storage, there is no abatement option to reduce or eliminate the process emissions inherent to the production of lime.
- Take large scale implementation of CCS only into account in the target setting when it has become feasible;
- Provide long term certainty;
- Consider to account for the effect of natural carbonisation (refer to 5.2.4). EuLA will continue to work to provide more insight.

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Annex Assumptions Table 9

The assumptions used to generate Table 9 are listed in this annex:

- The assessment is a simplified assessment, based on investment costs and changes to the fuel costs only. Neither changes in operation/maintenance costs, nor the possible advantage to increase capacity nor potential impacts on the quality of produced lime products are taken into account
- To annualize investment costs, a discounted payback time criterion of five years, a depreciation time of ten years, 2% inflation and 8,5% WACC has been used, accounting for 30% income tax (longer payback time criteria would lead to lower abatement costs);
- Investment costs for PFRK and use of biomass are based on a lime plant producing 100.000 ton/lime product a year, higher than the average capacity of current EU lime plants;
- Investment costs for PRK – which usually have a higher capacity – are based on an average of actual data;
- No distinction is made here between the different lime products, energy efficiency improvements and effects of kiln switches are based on quicklime specific energy consumptions;
- Energy prices are based on the EU energy prices for fuels as indicated in Table 3, with the exception of the price for solid fossil fuels (for which a price (at burner) of €5/GJ has been assumed to reflect the actual grades used by the lime industry); for biomass a price (at burner) of €7/GJ has been assumed (wood; cheaper forms are also locally available)[83];
- Mentioned investment costs (and hence abatement costs) always assume investing in new capacity *replacing old capacity before it reaches technical end-of-life*[84]*.* In practice, kilns for example receive big maintenance periodically and at these moments replacing a kiln would be more cost effective than indicated; therefore, these results would need to be checked case-by-case.
- In the calculations of the effects of changing the kiln types, it has been assumed that the same fuel mix is applicable[85], and that the new PFRK has the same efficiency as the average of PFRK's currently in use[86], while a new PRK has a higher efficiency than the average of the existing PRK's;
- For CCS, only costs for capture are included in the table, and data are based on a large plant case study (TNO, 2012) with current state-of-the-art solvent MEA as solvent[87]. Recent insights in more innovative technologies suggest cheaper processes could be chosen as well. For transport and storage, additional costs can be euro 15/ton CO_2 in case of large scale uptake of CCS, and assuming higher pay back times (ZEP, 2011a) (ZEP, 2011b);
- The abatement costs for all these measures decrease more or less significantly in case of longer pay back time periods (for example DPB of 10 years or higher); except CCS and Solid/liquid fossil

[83] As such, the fuel prices for the key fuels are listed here.

[84] This implies that it is assumed that in case the investment would not have been done, there would be no need for another investment to keep capacity constant. Therefore, the full investment costs for the new installation are taken into account.

[85] So, when horizontal kilns, currently mainly using solid fossil fuels, are replaced by PFRK's, these are also assumed to use solid fossil fuels. Likewise for the transition of LRK to PRK. The limitation that not all types of waste can be used in PFRK's is not taken into account.

[86] In case the energy consumption of the newly built PFRK's would be lower than the average of the PFRK's currently in use, the savings would increase and the abatement costs would decrease.

[87] And assuming an electricity price of €90/MWh, and a price of steam of ~ €11/GJ. In the numbers given for CCS capture, OPEX cost are taken into account (in line with (TNO, 2012)). The numbers on CCS Capture reflect the use of the state-of-the-art solvent (MEA), which is currently available. (TNO, 2012) also assesses a next generation solvent, which leads to higher conversions, at lower costs. In the future, further developments in technologies used to capture CO_2 could lead to further increases of the share of captured CO_2 at further cost decreases.

fuel to NG which remain insensitive to DPB period. Abatement costs – apart from CCS – are highly sensitive to the energy pri

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