EUFORIE
European Futures for Energy Efficiency

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European Futures for Energy Efficiency

Report on ASA analyses of energy efficiency at company level

WP6 Deliverable D6.1

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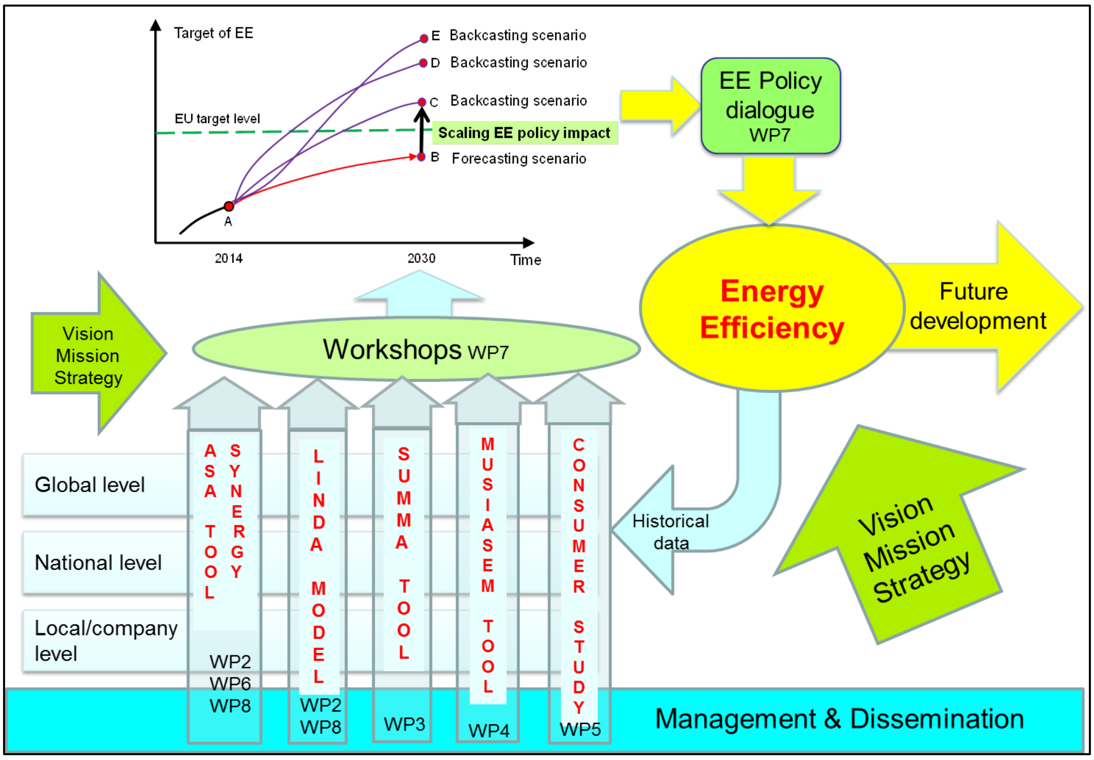
The EUFORIE project

The strategic goal of the EUFORIE project is to provide useful and accurate information and knowledge in the field of energy efficiency for the EU Commission and stakeholders in the Member States. The tangible objectives are the following:

1. To provide energy and energy efficiency trends and their drivers, synergies and trade-offs between energy efficiency related policies, as well as energy efficiency scenarios (WP2).
2. To provide data about implementation of energy efficiency in specific processes, sectors and entire systems, in order to understand bottlenecks/efficiency drops and suggest improvements (WP3).
3. To carry out analyses of efficiency of provision, from making useful energy carriers from primary energy sources, and from conversion of energy carriers to end uses across macro-economic sectors (WP4).
4. To identify policy instruments and other measures leading to significant reduction in the energy consumption of households (WP5).
5. To analyse the relationship between investments and change in energy efficiency, and to develop indicators to describe changing energy efficiency at the company level (WP6).
6. To carry out participatory foresight for European stakeholders of energy efficiency with a target of providing ideas for the energy efficiency vision and strategy in the European Union (WP7).
7. To compare energy efficiency policy instruments and measures and their impacts in China and the European Union (WP8).

The EUFORIE Work Packages relate to each other. The project applies different quantitative and qualitative analysis methods to energy efficiency in the EU and its Member States at different levels and from different perspectives. These analyses provide input for foresight activities, which serve European energy efficiency vision and strategy process by generating useful information. Management (WP1) and dissemination (WP9) run in parallel with the research and innovation activities.



Executive summary

The purpose of this deliverable is to study how energy efficiency has affected energy consumption, raw material consumption and environmental impacts at the company level. For this purpose, five case companies were selected by using the following criteria: (1) energy as a major production factor, and/or (2) energy as a major product, and (3) good availability of data from public sources (annual reports, environmental reports, sustainability reports, corporate social responsibility reports, websites, and databases. The selected companies include energy companies ENEL (Italy), RWE (Germany) and CNPC (China), and industrial companies Stora Enso (pulp and paper, Finland/Sweden) and Celsa Barcelona (metal products, Catalonia/Spain).

A chained two-factor decomposition analysis was used to carry out the research task. Several different analyses were made depending on the availability of data of different indicators at different levels in the case companies. Selecting different indicators for analysis offers an opportunity to receive a wide perspective to a company’s performance in terms of energy efficiency, material efficiency and environmental efficiency.

Publicly available data was used in the analyses. The selected data describes the performance of the company:

- the amount of production (total production and selected products/product groups in physical units)
- energy consumption (consumption of total energy and different energy carriers)
- raw material use (selected major raw materials), and
- environmental impacts represented by emissions into air such as CO_2, SO_2, NO_x emissions, and amount of waste.

The availability of time series data (required by the decomposition analysis) at different levels inside a company was very different in different case companies. The time period analysed covers the years from 2010 onwards in all case companies.

Several different decomposition analyses were carried out for all case companies. The results show that energy intensity, material intensity, or environmental intensity has in many cases decreased in the industrial and energy companies selected for this study. Many of the decomposition analyses show decreasing effects − sometimes very significant ones − to energy and material consumption, and especially to environmental impacts. Sometimes the decreased intensities have only been able to slow down the increase of energy and material consumption and environmental impact caused by the increasing amount of production. As a conclusion, at the company level, the most important driver of energy consumption, raw material consumption and environmental impacts, is the amount of production. It explains a vast majority of observed absolute changes in energy and raw material consumption and in environmental impacts – both decreases and increases.

The study also brought out several improvement possibilities to company reporting regarding the data describing their operational performance. Time series data on environmental indicators (such as emissions into air, water and soil, and waste), the use of different primary energy sources and different energy carriers, the use of major raw materials, and the amount of production (in both physical and monetary units) would enable a proper decomposition analysis of company performance. Even more beneficial could be if the data would be available also for individual production sites, for different production processes, or even for individual products.

The results are useful for industry, and especially for the selected case companies. The results may benefit all companies interested in improving their external communication via publicly available reports as well as databases and data management tools. The methodological approach is useful of researchers in the fields of environmental management and environmental policy. The results offer an insight at the company level also for policy makers in the EU and in individual Member States.

Tasks of this deliverable related to WP6 and WP8

This deliverable D6.1 covers the following tasks in EUFORIE WP6 (Microeconomic efficiency analysis of selected case companies) and in EUFORIE WP8 (Chinese energy efficiency and comparison of European/Chinese policy effectiveness):

- Task 6.1 “Selecting of case companies, collecting company level data related to energy efficiency from public sources and directly from selected companies, and carrying out the empirical ASA analysis” of EUFORIE WP6 “Microeconomic efficiency analysis of selected case study companies”, and
- Task 8.5 “Company level analysis” of EUFORIE WP8 “Chinese energy efficiency and comparison of European/Chinese policy effectiveness”.

In addition, this deliverable has also a link to EUFORIE WP3 (Regional case studies of energy efficiency in Europe) Task 3.1 Process level), where one of this deliverable’s case companies has provided data for an LCA study.

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Abbreviations

Abbreviation	Explanation
ASA	Advanced Sustainability Analysis
AOX	Absorbable Organic Halogen
BOD	Biological Oxygen Demand
CBA	Cost-benefit analysis
CHP	Combined heat and power production
CO_2	Carbon dioxide (emissions)
COD	Chemical Oxygen Demand
EASME	Executive Agency for Small and Medium-sized Enterprises
EC	European Commission
EN	Energy use
ES	Environmental impacts (environmental stress)
EU	European Union
EUFORIE	European Futures for Energy Efficiency
EUR	Euro(s), €
GDP	Gross Domestic Product
GJ	Gigajoule (10^9 joules)
GW	Gigawatt (10^{12} watts)
GWh	Gigawatt-hour (10^6 kilowatt-hours)
IEA	International Energy Agency
kWh	kilowatt-hour
LCA	Life-cycle assessment/analysis
m^2	Squaremeter
m^3	Cubicmeter
MJ	Megajoule (10^6 joules)
Mtoe	Million tonnes of oil equivalent
MW	Megawatt (10^6 watts)
MWh	Megawatt-hour (1000 kilowatt-hours)
NEEAP	National energy efficiency action plan
NO_x	Nitrous oxide(s) (emissions)
N_2S	Nitrous sulfite
PJ	Petajoule (10^{15} joules)
PROD	Amount of production
RM	Amount of raw materials
SME	Small or medium-size enterprise
SO_2	Sulphur dioxide (emissions)
TJ	Terajoule (10^{12} joules)
TWh	Terawatt-hour (10^9 kilowatt-hours)
VA	Value added
WP	Work Package

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Goals of this deliverable

In this EUFORIE deliverable D6.1, the focus is on energy efficiency at the company level. Energy consumption of a company depends on two major things: the amount of production, and the energy efficiency of the company's production process. Among other things, energy efficiency of a production process is a technical issue. A detailed technology-specific analysis, however, is not the purpose of EUFORIE WP6 and its deliverables. Instead, the perspective taken to the companies in this deliverable is an external one. The goal is to look at energy efficiency's role in the selected case companies' energy and raw material consumption. Moreover, the goal is also to find out how energy efficiency influences to environmental impacts.

To reach these goals, a decomposition analysis based on the publicly available data from selected case companies is used. This adds an important policy relevant perspective to the EUFORIE project: company reporting. The idea is to find out and make suggestions how company reporting could be improved, in order to provide sufficient information and time series data suitable for energy efficiency analysis, with a special reference to the decomposition analysis method used in this deliverable and the EUFORIE project.

Policy context: Energy efficiency policies in the EU

Energy efficiency is a means to tackle energy-related negative impacts such as harmful emissions in the air, but in the policy context it has gained a status of a target even as such. Energy efficiency can be improved in both energy production and consumption, and there are many technologies and policy instruments available for it (see Future Energy 2017; ODYSSEE-MURE 2017, for example). Based on the EU directive on energy efficiency (EC 2012), the EU Member States are currently preparing their next National Energy Efficiency Action Plans (NEEAPs), where they set out the estimated energy consumption, planned energy efficiency measures, and the improvements the EU Member States expect to achieve. The Member States report their achievements in the Annual Reports.

Table 1. Projected energy consumption in the EU Member States in the year 2020 (EC 2017; primary/final energy consumption ratio added by the authors).

EU Member State	Energy consumption in 2020 as notified from Member States in 2013, in the NEEAP 2014 or in a separate notification to the European Commission in 2015		
	Primary energy consumption, Mtoe	Final energy consumption, Mtoe	Primary/final energy ratio
Austria	31.5	25.1	1.25
Belgium	43.7	32.5	1.34
Bulgaria	16.9	8.6	1.97
Croatia	11.5	7.0	1.64
Cyprus	2.2	1.8	1.22
Czech Republic	39.6	25.3	1.57
Denmark	17.8	14.8	1.20
Estonia	6.5	2.8	2.32
Finland	35.9	26.7	1.34
France	219.9	131.4	1.67
Germany	276.6	194.3	1.42
Greece	24.7	18.4	1.34
Hungary	24.1	14.4	1.67
Ireland	13.9	11.7	1.19
Italy	158.0	124.0	1.27
Latvia	5.4	4.5	1,20
Lithuania	6.5	4.3	1.51
Luxembourg	4.5	4.2	1.07
Malta	0.7	0.5	1.40
Netherlands	60.7	52.2	1.16
Poland	96.4	71.6	1.35
Portugal	22.5	17.4	1.29
Romania	43.0	30.3	1.42
Slovakia	16.4	9.0	1.82
Slovenia	7.3	5.1	1.43
Spain	119.8	80.1	1.50
Sweden	43.4	30.3	1.43
United Kingdom	177.6	129.2	1.37
Sum of indicative targets EU-28	*1526.9*	*1077.5*	*1.42*
EU-28 target 2020	*1483.0*	*1086.0*	*1.37*

Based on the 2014 NEEAPs, the EU has provided a document where the estimated primary and final energy consumption as well as the 2020 targets have been presented for all EU-28 Member States (Table 1). The targets set individually by the Member States are tied to the target of the whole EU.

On 30 November 2016 the Commission proposed an update to the Energy Efficiency Directive, including a new 30 % energy efficiency target for 2030, and measures to update the Directive to make sure the new target is met (EC 2016). This is a current and important issue in national energy policies of the EU Member States.

Successful implementation of energy efficiency policies at national level in the EU-28 Member States means decreasing energy consumption in different economic sectors such as agriculture, industry, energy, construction, services, households, transport etc. Productive action in these sectors takes often place in companies, and nowadays companies exist in all economic sectors. In this deliverable, the sectoral focus is in companies where energy is a significant production factor. These companies belong to the energy and industrial sectors.

Case companies

Selection of companies

The case companies have been selected by the EUFORIE consortium partners. Selection took place after the start of the project. The criteria for selection included (1) energy as a significant production factor, or energy as a significant product, and (2) good availability of production-related company-level data in publicly available company reports (annual reports, environmental/sustainability reports, and corporate social responsibility reports). The content and quality of these reports are evaluated from the point of view of data availability for the decomposition analysis of energy use, with special reference to the effect of changing energy efficiency to energy consumption and environmental impacts. The policy relevance of EUFORIE WP6 comes primarily from the evaluation of company reporting, not from the analysis of technical efficiency of production processes in the companies, which is a process-specific issue.

In this deliverable, the case companies have been called by their real names, because all data used in the analysis is publicly available. Identification of the companies is not essential for fulfilling the goals of this deliverable, because the purpose is not to make detailed company-specific energy efficiency evaluation but look at how the decomposition analysis in the Advanced Sustainability Analysis (ASA) approach can be applied to companies in the light of publicly available data. Further goal of EUFORIE WP6 is to develop a useful generic indicator for monitoring development in energy efficiency of companies, and the next deliverable D6.2 deals with it.

The recommendations of this deliverable will deal, in addition to the decomposition results, with the company reports targeted to the external audience, especially with the relevant content of environmental, sustainability and corporate social responsibility reports from the perspective of generic energy efficiency information. The company level is actually a multi-level thing; these levels vary from a technology-specific production process inside one production facility to an international or even global concern as a whole, with operation in numerous countries all over the World.

It is necessary to point out, that if the purpose of EUFORIE WP6 had been to carry out company-specific energy efficiency monitoring from the company’s internal perspective, contact to the companies at a very early stage and their engagement to the project well before submitting the initial application would have been of great importance. This, however, was not the idea when the EUFORIE application was prepared. The idea was just to take the first steps in applying decomposition analysis to companies.

The outcome of this deliverable includes recommendations for company reporting. Here only big companies have been used as examples, but recommendations are valid also in SMEs, which too often do not provide any publicly available information about their energy use and environmental impacts.

Company descriptions

Stora Enso

Stora Enso is a large international producer of paper and board, biomaterials, and wood products. The company employs around 25,000 people globally. In 2016, the company's sales amounted to a total of EUR 9.8 million. The company markets itself as a leading expert in the development of climate-friendly products and services.

The most energy-intensive processes in the company's value chain include pulp and paper/board production processes. The company is committed to continuous improvements in energy efficiency and energy self-sufficiency. In 2016, energy self-sufficiency was above 60 % and electricity self-sufficiency was above 40 %. As for the purchased electricity, approximately 90 % was generated using low-carbon production technologies such as nuclear power and renewable energy. The majority of production units use considerable amounts of biomass as an internal source of energy. Biomass used for internal energy production originates from by-products and residuals from the units' own processes. Energy accounted for 10 % of the company's variable costs in 2016.

In 2008, the company started an energy efficiency investment fund to support projects that promote energy efficiency. It has invested between EUR 10 million and EUR 15 million annually in energy efficiency projects between 2013 and 2016.

The company has established energy guidelines as a part of company policies to direct energy procurement and energy generation choices in the long term, and promote responsible energy management. The company has also certified several of its production units – corresponding to over 90 % of its total energy consumption – to the ISO5001 energy efficiency management standard.

The company has established multiple short-term and long-term sustainability targets for energy efficiency and CO_2 emissions. For energy, the company aims at a 15 % reduction in electricity and heat consumption per sealable ton of pulp, paper and board by 2020 compared to the baseline of 2010. Similarly, a reduction of 35 % in CO_2 emissions per sealable ton of pulp, paper and cardboard is targeted by the end of 2025 in comparison to the benchmark of 2006. This target was reported to be achieved.

The main atmospheric emissions generated by the company are attributed to the combustion of fossil fuels throughout the value chain of its products. The main emissions include CO_2, SO_2 and NO_x, and fine particle emissions. The emissions generated by the company's production units are regulated by relevant authorities and limited local conditions and legislation.

The company prolonged the voluntary commitment to the Energy Intensive Industries Agreement managed by the Confederation of Finnish Industries, whereby it aims to reduce energy use at the Finnish production units by 4 % over the period 2017-2020 and by 3.5 % over the period 2021-2025.

In publicly available reports from Stora Enso, the data availability for the purpose of this deliverable is quite good at the level of the whole company. Production data is available for major product groups (of the four divisions). Energy data is available for the whole company as aggregates and in the form of energy mixes for fuel and electricity. Raw material data on wood and other raw materials such as pigments, fillers and starch is available, as well as data on water consumption. Environmental data is available on emissions into air (CO_2, SO_2 and NO_x emissions), discharge to water (phosphorous, nitrogen, AOX and COD), and amount of waste (including the shares of different waste treatment alternatives). Data on investments is also available, but the categories of investment types are different in different years.

Division-based publicly available data is limited to economic indicators, production/deliveries and number of employees only. Data of environmental impacts (e.g. CO_2, SO_2, NO_x emissions, and waste) is available at the level of production units/sites all over the world. Process-specific data is not publicly available. Data for a LCA of printing paper was provided by Stora Enso in the context of EUFORIE WP3, but this data is for one year (2015) only, so it cannot be used for decomposition which focuses on change over time. The LCA study is available in EUFORIE deliverable D3.1.

The data on Stora Enso used in this deliverable is gathered from Stora Enso annual reports 2010-2016, Sustainability Reports 2015-2016 and Global Responsibility Reports 2010-2014.

ENEL

ENEL (Ente nazionale per l'energia elettrica) is one of the largest multinational producers and distributors of electricity and gas internationally, with a large presence throughout Europe, North America, Latin America, Africa and Asia. This company operates in more than 30 countries and employs over 60,000 people globally. The company has a net installed capacity that exceeds 80 GW and provides energy and services for over 60 million customers in various locations. In 2016, the company sold over 250 GWh of electricity and delivered more than 10 billion m^3 of gas. In 2015, the company was listed as one of the 50 companies capable of changing the world by Fortune.

The company has committed itself to the ambitious target of becoming completely carbon neutral by 2050. The company is involved in various projects in the renewable energy sector, and describes itself as a front-runner in the development and use of new energy technologies. It aims at making energy more reliable, affordable and sustainable, which is seen through the strong involvement in renewables, namely in solar, wind, hydro, geothermal, biomass and cogeneration plants. In 2016, the total installed capacity from renewables was well over 30 GW.

As part of the targets set for the decarbonization of its energy mix, the company has committed itself to reducing the specific CO_2 emissions to a level below 350 g per kWh generated, which corresponds to a reduction of 25 % in comparison with the baseline of 2007. In addition, the company plans to incorporate some 8 GW of additional renewable energy capacity between 2017 and 2019 and to reduce thermal capacity by more than 10 GW in the same time period.

In the publicly available reports from ENEL, the availability of company level data for the purpose of this deliverable is relatively good. Energy data includes gas sales, electricity generated by energy source (total generation also by geographical area), and primary energy consumption by energy source. Environmental data includes CO_2, NO_x, SO_2, H_2S and particulate matter emissions, waste (including hazardous waste), and data on emissions of ozone depletion substances is available as well.

Data per geographical business areas is available on economic indicators and on production by type of production facility. Facility-specific data is not available in the public reports.

The data on ENEL used in this deliverable is gathered from ENEL annual reports 2010-2015, Sustainability Reports 2010-2015 and Environmental Reports 2010-2015.

RWE AG

RWE (formerly Rheinisch-Westfälisches Elektrizitätswerk AG) is one of the key electricity and gas utilities in Europe with a customer base that exceeds 16 million for electricity customers and 7 million for gas customers. The company employs around 60,000 people internationally. In addition to the main products, the company also provides other services such as energy advice, photovoltaic systems, storage facilities, electric mobility solutions and automation technology.

The company is organized into three main branches that each specialize in one area of the business, namely conventional power generation, supply and trading, and renewable energy.

The company currently has an installed power generation capacity of over 40,000 MW. For conventional power generation, the main raw materials used are hard coal, lignite and gas.

The company claims to actively pursue the achievement of sustainability goals in the future to comply with national and EU objectives. In 2013, the company introduced an energy management system that is in compliance with the ISO5001 Energy Efficiency management standard with a 100 % coverage of nearly 70 % achieved so far.

As it is an energy utility with a high proportion of fossil combustion fuels in power generation, the company has identified climate protection and greenhouse gas emissions reduction as critical areas to improve and has committed itself to making its power generation plants more efficient as part of its strategy to comply with the European climate protection targets. The main gas emissions generated from conventional power production include CO_2, SO_2, NO_x and dust emissions. The company intends to reduce its emissions from electricity generated in its lignite-fired power plants by 15 % by 2020, with additional reductions and an increased share of renewables in the total energy production by 2030.

The data availability for the purpose of this deliverable is good at the company level. The RWE webpage has recently introduced a data management tool, and operational time series data is now available from the year 2006 onwards. In addition to company level, the data enables some decomposition analysis also per primary energy sources of electricity production.

Other levels include countries of operation and individual production facilities/power plants. Data on other levels is limited mostly to economic indicators and production in the countries of operation. Facility-specific operational data is not available in the public reports.

All data on RWE used in this deliverable is gathered from the RWE Data Management Tool.

Celsa Barcelona

Celsa Barcelona is a metallurgical company that specializes in the production of steel plates, wire rods, channels and electro-welded mesh products. The company has an annual production capacity of approximately 2.5 million tonnes of steel products. The company claims to produce nearly all its products from recycled scrap. The production units consist of two electric ovens of nearly 300 tonnes in capacity and 3 main production lines that specialize in diverse products, along with 2 additional, smaller production lines. Celsa Barcelona is a part of the international Celsa Group.

The most important resources consumed during the company’s activities are electricity, natural gas, scrap, water, steel alloys and oils. The electricity consumed is mainly generated by thermal electric plants and nuclear plants.

The company envisions to be a leading model in the metallurgical sector and is committed to actions that improve its overall sustainability. The company plans to reduce its energy consumption, and currently invests in projects that promote technological innovation and environmental sustainability at all stages of its value chain through measures to prevent the contamination of its surroundings, development of energy technologies, reduction of energy consumption, limiting of its atmospheric emissions, noise reduction and minimization of residual waste. The company works on reducing the environmental impact of its activities through legal commitments and voluntary agreements.

The data availability for the purpose of this deliverable is rather limited. Celsa Barcelona publishes its own reports with some relevant environmental data (such as emissions in the air, water consumption and the amount of waste) which is presented for four different groups of steel products. Good thing is that each report includes time series data. However, the amount of production per product group is not available, only the total production is included. Energy consumption and CO_2 emissions are available for the product groups too, but the latter in a form of an index number (2010=100) only. In the report, the data is presented in graphs only. However, some decomposition analyses are possible at the level of the four product groups.

The data on Cesla Barclona used in this deliverable is gathered from Celsa Barcelona Environmental reports 2014-2015.

China National Petroleum Corporation (CNPC)

CNPC (China National Petroleum Corporation) is a large, Chinese state-owned integrated energy corporation that operates internationally in nearly 40 countries. Its main products and services include oil and gas exploration and development, refining and chemicals, marketing and trading, pipeline transmissions and stockpiling, technical services, engineering construction, equipment manufacturing and financial services. The company’s annual oil and gas production exceeds 250 million tonnes of oil equivalent.

The company promotes itself as an enterprise that strives to tackle the energy challenges in the future and meet the demand for low-carbon, clean energy at an affordable price while also ensuring that the quality of their products meets the standard requirements. For this purpose, the company has created partnerships with the Government and other companies, and invested considerable effort in technological innovation and the improvement of energy efficiency in hydrocarbon development and utilization.

As part of its strategic development, CNPC has actively invested growth-oriented projects for the development of its natural gas business in the recent years and expanded its domestic and transnational pipeline networks for natural gas.

The company is a supporter of the Paris Agreement and national programmes to address climate change. It is aiming at lowering its carbon emissions through restructuration of its businesses, the development of clean energy, the improvement of energy efficiency and the strengthening of research initiatives for low carbon technologies and carbon sequestration. The company also currently explores new possibilities for clean energy through the development of geothermal, solar and other renewable energy sources.

In the case of CNPC, the availability of data for the purposes of this deliverable is limited. The company has published data on environmental impacts (emissions and waste) only in the 2015 report, but the data does not include CO_2 emissions. The only time series data is available on oil pollutants in wastewater. In principle, CO_2 emissions can be calculated from the data of used fuels in the case of combustion processes, but in CNPC the most important production process is oil refinery. Although some data is distinguished between domestic and overseas, decomposition analyses are possible only at the level of the whole company.

The data on CNCP used in tis deliverable is gathered from CNCP Annual Reports 2010-2015.

Methodology of energy efficiency analysis at the company level

Definition of energy efficiency at company level

In general systems perspective, efficiency refers to a relationship between the input and output of a defined system. Change of efficiency over time brings out the common efficiency idea of "getting more from less", which explains the fact that improving energy efficiency has been a common energy policy goal all over the World from the 1970's oil shocks. Using less energy for a certain task decreases energy consumption and related costs. Attention is paid to energy costs especially when energy price is increasing.

In companies, energy is an input of the production system (process). Energy efficiency refers to a relationship between the energy input to the system and the output of the system (Equation 1):

$$Energy\ efficiency = \frac{Output}{Energy\ input} \qquad (1)$$

When energy input is decreased but the output remains the same, energy efficiency increases. This kind of definition is valid in all systems, and it is not dependent on any scale or type of system *per se*. However, in practice, the system boundary must be clearly defined. In large systems, the energy input usually consists of different energy sources such as electricity, heat, or different types of fuels. Energy efficiency of a system requires that the total energy input to the system is considered. Thus in large systems, the use of aggregate energy units is relevant. On the other hand, also the output should be considered in total terms, which makes the use of monetary units attractive if the physical units cannot be easily aggregated. One can argue that different energy sources or different outputs should not be aggregated, which is a relevant argument because aggregation always loses information. In EUFORIE WP4 a method taking this into account is suggested for macro level analyses, and it can be applied to companies as well. In this deliverable that approach is not used, but it is an important topic for further research.

The inverse of energy efficiency is energy intensity (Equation 2)

$$Energy\ intensity = \frac{Energy\ input}{Output} \qquad (2)$$

Energy input in both Equations (1) and (2) refers to energy use inside the boundaries of the studied system. Change in energy use, on the other hand, is not necessarily a result of change in energy efficiency or energy intensity alone, it depends also on the activity level of the system, and on the structure of the different activities included in the studied system (Kasanen 1990). Moreover, energy use may also change if the structure of the energy mix changes. But in general, change in energy use is a result of an activity effect, an intensity effect, and a structural effect. In this deliverable, the intensity effect is in the focus.

ASA decomposition

The Advanced Sustainability Analysis (ASA) is an approach based on the IPAT identity. The IPAT identity emerged out of the Ehrlich & Holdren/Commoner debate in the early 1970s about the driving forces of global environmental impacts (York et al 2003). The IPAT identity identifies the major drivers of environmental impact (I) at the global level: the amount of population (P), the affluence of that population (A), and level of technology (T). Waggoner and Ausubel (1992) added a new term, consumption (C) in the identity and called the result as an ImPACT identity. Kaya (1990) applied the idea of IPAT identity to identify the drivers of climate change and carbon dioxide emissions. His application has been called as Kaya identity, which has had an influence also to the ASA approach.

Advanced Sustainability Analysis (ASA) is a mathematical information system developed by Finland Futures Research Centre (see e.g. Malaska et al 1999; Kaivo-oja et al 2001a; 2001b; Vehmas et al 2003; Luukkanen et al 2005). The ASA approach can be used to analyze sustainable development from different points of view. The focus is on changes over time between economic and environmental, economic and social, and social and environmental dimensions of sustainability which can be measured with any preferred indicator or index (Figure 1). The choice of indicators enables the use of ASA approach to specific topics such as energy efficiency in the EUFORIE project. The ASA approach can be applied to all levels of economic activity, from company level to national even to global level. In EUFORIE WP6, it will be applied first time to companies.

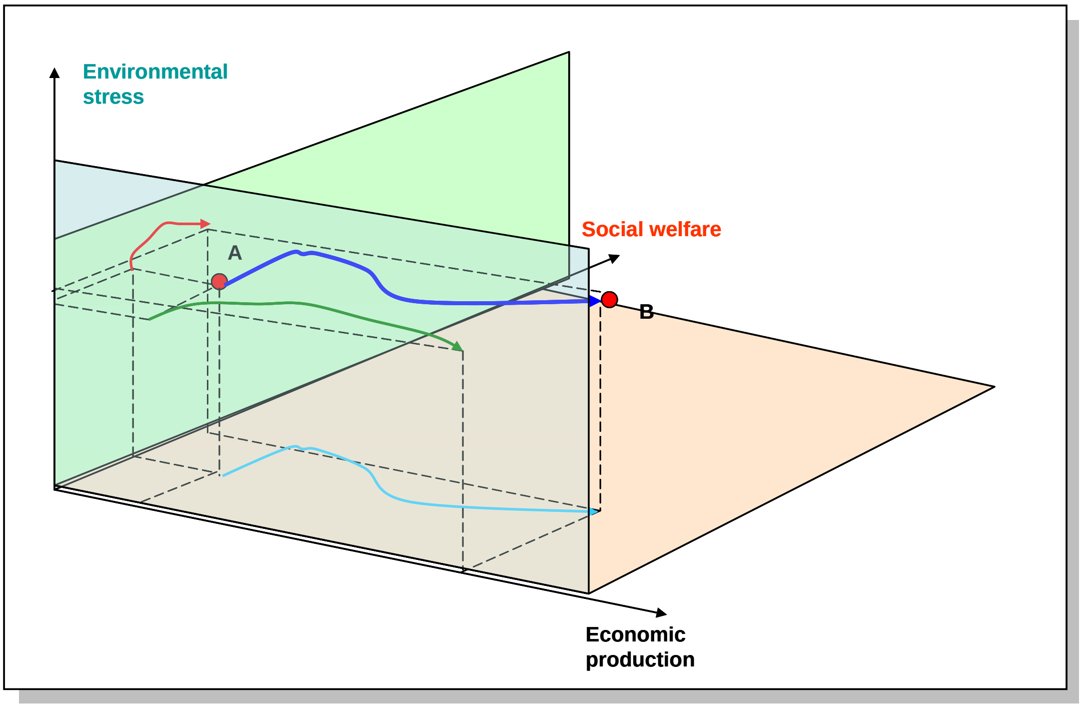


Figure 1. ASA analysis in the different dimensions of sustainability.

The ASA approach has been introduced in the EUFORIE WP2 deliverable D2.1 as well as in deliverables of previous EU projects DECOIN (Development and Comparison of Sustainability Indicators, FP6, see http://www.decoin.eu) and SMILE (Synergies in Multi-Scale Eco-Social Systems, FP7, see http://www.smile-fp7.eu), coordinated by University of Turku. In the EUFORIE project (D2.1), instead of a cumulative decomposition with a fixed base year (used in the previous EU projects and in the above mentioned publications), a more precise incremental decomposition based on annual changes and using a moving base year has been introduced. Incremental decomposition is used also in this deliverable.

The objectives of the ASA approach include the following:

(1) to identify factors contributing to a change in a studied (environmental, social or economic) sustainable development indicator
(2) to estimate the contribution of each factor to the studied change in quantitative terms
(3) define and operationalize new concepts related to sustainable development
(4) to answer policy-relevant "what if" type questions related to sustainable development objectives.

The ASA approach is capable of providing tools to fulfil objectives (2), (3) and (4). Objective (1) requires something else, such as theoretical and/or empirical evidence related to the studied phenomena. In the EUFORIE project, especially objective (2) is in the focus, because the ASA approach can be used to analyse the effects of energy efficiency indicators on relevant energy policy goals, such as those related to energy consumption and CO_2 emissions from fuel combustion. In the analysis of sustainable development, energy efficiency is an important driver. What drives energy efficiency, is another question where the price of energy, technological development and Governmental policies play a major role.

ASA applies decomposition analysis in order to divide the observed change in environmental, social or economic indicators into the effects of contributing factors. Identifying the contributing factors in the format required by the ASA approach may be challenging, because selection of potential factors must be supported by theoretical or empirical arguments not based on the ASA approach. The approach itself does not support or give tools for factor identification, so it is based on either theory-based or assumed causal relationship between the identified factors and the studied indicator.

In addition to change in the values of the studied indicator over time, i.e. between time moments *t-1* and *t* (presented as change in area $\Delta ES_{tt-1} = ES_t - ES_{t-1}$ in Figure 2), the required data consists of values for so-called extensive variables describing change in the size of the studied system (variable X in Figure 2). The extensive variables (X_n , n≥1) can be used to create a series of so-called "intensive" type of variables such as X_{n-1}/X_n, n≥2 (variable ES/X in Figure 2). Typically, these variables may be characterized as "intensities", "efficiencies" or "productivities", depending on the choice of different extensive variables. The sum of the decomposed results (presented as areas in Figure 2), i.e. the contributions of all identified factors, is equal to the total change in the studied environmental, social or economic indicator (area ΔES in Figure 2).

In this basic two-factor decomposition, by choosing energy consumption as variable ES and GDP as variable X, ES/X is energy intensity, which is an inverse of energy efficiency. Variable X has been called in the ASA approach as a gross rebound effect (to separate from energy economists' rebound effect which is not a macro level concept). It can be considered as an empirical operationalization of the Jevons paradox..

The decomposition analysis calculates the effect/contribution of each explaining factor and their "joint effect" (residual term), which in a complete decomposition must be allocated to the two explaining factors. Figure 2 defines different alternatives for allocating the joint effect: Parameter λ defines the share of the joint effect allocated to the effect of intensive variable ES/X, and 1-λ defines the rest allocated to the effect of extensive variable X.

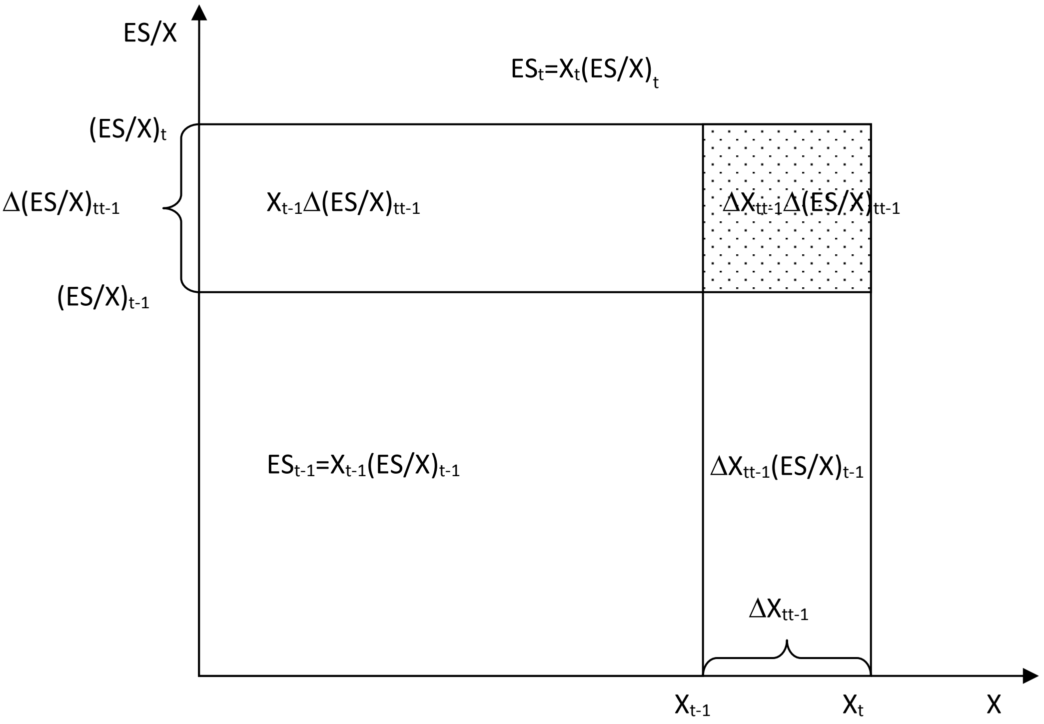


Figure 2. The separate effects of changes in variable X and variable ES/X, and the joint effect of changes in variables X and ES/X to the total change of ES (modified from Sun 1996, 48). The difference between the size of rectangles ES_t and ES_{t-1} represents the change in variable ES between time moments t-1 and t..

When λ=0 the joint effect is allocated totally to the effect of variable X, and λ=1 allocates it totally to the effect of variable ES/X. A value of λ=0.5 allocates the joint effect "equally" to both effects (Sun 1998). However, any value between 0 and 1 ($0 \leq \lambda \leq 1$) can be given to the parameter λ. The allocation can, for example, made in relation to the relative changes of the contributing effects compared e.g. to their base year values (Equation 3):

$$\lambda = \frac{\left| \dfrac{\Delta\left(\dfrac{ES}{X}\right)_{tt-1}}{\left(\dfrac{ES}{X}\right)_{t-1}} \right|}{\left| \dfrac{\Delta\left(\dfrac{ES}{X}\right)_{tt-1}}{\left(\dfrac{ES}{X}\right)_{t-1}} \right| + \left| \dfrac{\Delta X_{tt-1}}{X_{t-1}} \right|} \tag{3}$$

What is the right value for parameter λ? The choice of the parameter value affects the result, depending on the actual changes in the indicator values selected for investigation (cf. Figure 3). In spite of this, the decomposition where the ASA approach stems from, is based on the choice λ=0. Sun (1996; 1998) has preferred the choice of λ=0.5, which is also selected for the value of all λ parameters in the decomposition analyses carried out in the EUFORIE project. This choice is essential in the so-called Sun/Shapley decomposition method, which is considered as one of the preferred methods by Ang (2004).

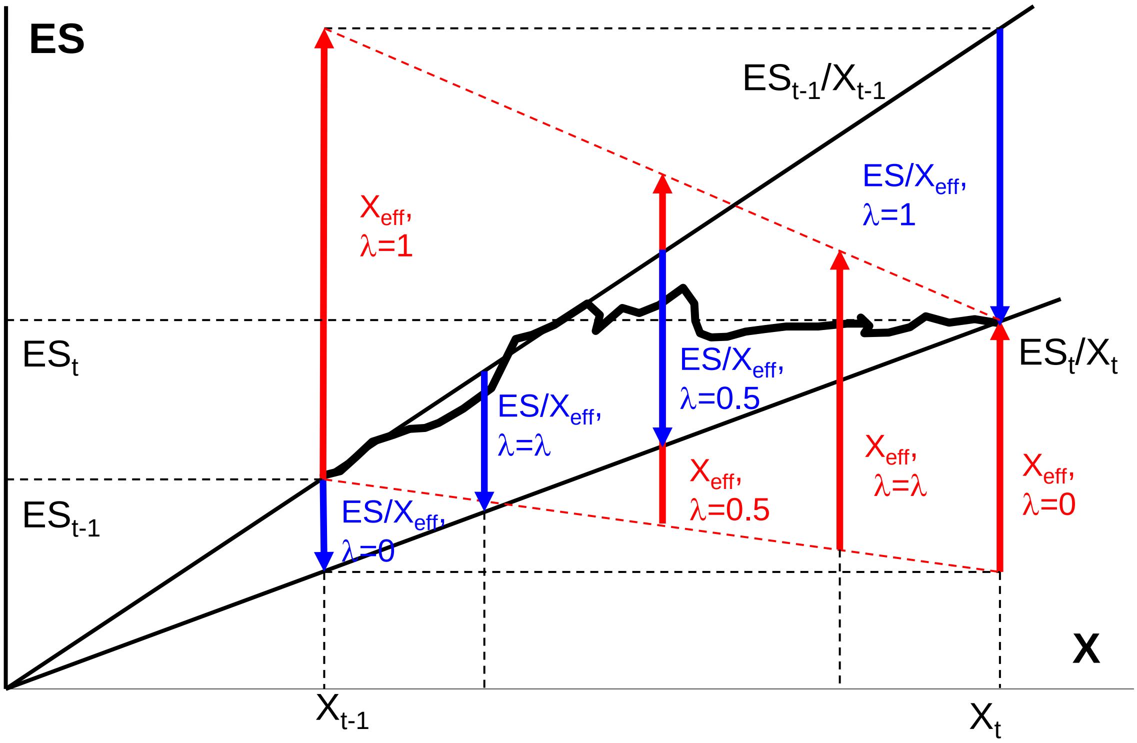


Figure 3. Decomposition of change in variable ES into the contributions of variables X and ES/X by using different values for parameter λ. In the empirical analyses of this report, value λ=0.5 will be used.

In general terms, the contributions of variables ES/X and X, $(ES/X)_{eff}$ and X_{eff} can be calculated by using the following Equations (4-6b):

$$ES = \frac{ES}{X} \times X \tag{4}$$

$$\Delta\left(\frac{ES}{X}\right)_{tt-1} = \left(\frac{ES}{X}\right)_{t} - \left(\frac{ES}{X}\right)_{t-1} \tag{5a}$$

$$\Delta X_{tt-1} = X_t - X_{t-1} \tag{5b}$$

$$\left(\frac{ES}{X}\right)_{eff} = \left(X_{t-1} + \lambda \Delta X_{tt-1}\right) \times \Delta\left(\frac{ES}{X}\right)_{tt-1} \tag{6a}$$

$$X_{eff} = \left[\left(\frac{ES}{X}\right)_{t-1} + (1-\lambda)\Delta\left(\frac{ES}{X}\right)_{tt-1}\right] \times \Delta X_{tt-1} \tag{6b}$$

These Equations (4-6b) and Figure 3 clearly show the allocation effect caused by the choice of parameter λ ($0 \leq \lambda \leq 1$).

Results of the first two-factor decomposition can be taken as a starting point for further decomposition. This enables taking more factors into account because this “chaining” can be repeated as many times as needed in order to get all the identified factors included in the decomposition Equation (“master equation”) taken into account (Equation 7):

$$ES = \frac{ES}{X_1} \times \ldots \times \frac{X_{n-1}}{X_n} \times X_n \tag{7}$$

where $n \geq 1$. Interpretation of the drivers is an empirical issue depending on the choices made for ES and X_n, but typically the drivers include one extensive-type (X_n) and one or more intensive-type variable(s) (X_{n-1}/X_n). Each empirical analysis provided in this deliverable includes analysis-specific interpretations of the corresponding drivers.

It should be noted that the order of adding new factors ($X_1 \ldots X_n$) in the chain when carrying out the decomposition analysis is determined by the theory, or assumptions, behind factor identification. In the following, chained decomposition analysis will be carried out by chaining extensive variables (X_n) in the order presented in the Equation (7).

In this deliverable, like in deliverable D2.1, ASA decomposition is made for annual changes with a moving base year (“incremental” decomposition analysis). Longer time periods can then be analysed by summing up the annual values during the longer time periods.

The decomposed effects of the factors identified in Equation (7) are calculated as follows in Equations 8-10. In the Equations, three extensive variables are included to have four drivers of change in the variable ES. In other words, change in ES is in the first decomposition a sum of changes in either the factors ES/X_1 and X_1, and after the second decomposition a sum of changes in ES/X_1, X_1/X_2 and X_2, and after the third decomposition a sum of changes in ES/X_1, X_1/X_2, X_2/X_3 and X_3:

$$\left(\frac{ES}{X_1}\right)_{eff} = (X_{1(t-1)} + \lambda_1 \Delta X_{1(tt-1)}) \times \Delta\left(\frac{ES}{X_1}\right)_{tt-1} \tag{8a}$$

$$X_{1(eff)} = \left[\left(\frac{ES}{X_1}\right)_{t-1} + (1-\lambda_1)\Delta\left(\frac{ES}{X_1}\right)_{tt-1}\right] \times \Delta X_{1(tt-1)} \tag{8b}$$

$$\left(\frac{X_1}{X_2}\right)_{eff} = \left[\left(\frac{ES}{X_1}\right)_{t-1} + (1-\lambda_1)\Delta\left(\frac{ES}{X_1}\right)_{tt-1}\right] \times (X_{2(t-1)} + \lambda_2 \Delta X_{2(tt-1)}) \times \Delta\left(\frac{X_1}{X_2}\right)_{tt-1} \tag{9a}$$

$$X_{2(eff)} = \left[\left(\frac{ES}{X_1}\right)_{t-1} + (1-\lambda_1)\Delta\left(\frac{ES}{X_1}\right)_{tt-1}\right] \times \left[\left(\frac{X_1}{X_2}\right)_{t-1} + (1-\lambda_2)\Delta\left(\frac{X_1}{X_2}\right)_{tt-1}\right] \times \Delta X_{2(tt-1)} \tag{9b}$$

$$\begin{gathered}\left(\frac{X_2}{X_3}\right)_{eff} = \left[\left(\frac{ES}{X_1}\right)_{t-1} + (1-\lambda_1)\Delta\left(\frac{ES}{X_1}\right)_{tt-1}\right] \times \left[\left(\frac{X_1}{X_2}\right)_{t-1} + (1-\lambda_2)\Delta\left(\frac{X_1}{X_2}\right)_{tt-1}\right] \times \\ \left(X_{3(t-1)} + \lambda_3\ \Delta X_{3(tt-1)}\right) \times \Delta\left(\frac{X_2}{X_3}\right)_{tt-1}\end{gathered} \tag{10a}$$

$$\begin{gathered}X_{3(eff)} = \left[\left(\frac{ES}{X_1}\right)_{t-1} + (1-\lambda_1)\Delta\left(\frac{ES}{X_1}\right)_{tt-1}\right] \times \left[\left(\frac{X_1}{X_2}\right)_{t-1} + (1-\lambda_2)\Delta\left(\frac{X_1}{X_2}\right)_{tt-1}\right] \times \\ \left[\left(\frac{X_2}{X_3}\right)_{t-1} + (1-\lambda_3)\Delta\left(\frac{X_2}{X_3}\right)_{tt-1}\right] \times \Delta X_{3(tt-1)}\end{gathered} \tag{10b}$$

The chaining can be continued further by adding new variables (X_n) to the master equation, and the new effects are calculated continuing the same logic. In all equations presented in this chapter, subscript *tt-1* refers to a change between a calendar year *t* and the previous year *t-1*. Coefficients $\lambda_1 \ldots \lambda_3$ define how the joint effect of the two variables are divided into the corresponding factor in each two-factor decomposition. Values for each of these coefficients can be chosen freely between 0 and 1 ($0 \leq \lambda_n \leq 1$). Choosing $\lambda_1=\lambda_2=\lambda_3=0$ always allocates the "joint effect" to the factor which will be further decomposed. This choice could be easily preferred from the chaining perspective. However, in all decomposition analyses carried out in this deliverable, the choice will be $\lambda_1=\lambda_2=\lambda_3=0.5$. This is because of support in the literature (see Ang 2004). As pointed out earlier, choice of the coefficient value(s) has a small effect on the results.

In the next chapters, master equations or ASA decomposition are presented for three basic variables, where energy efficiency has a role as a driver. In the case of industrial companies, where energy is not a product, energy use and environmental impacts are decomposed. In energy companies, where energy is a product (energy carriers such as electricity, heat, and commercial fuels), energy use refers to "own energy use" which is marginal in comparison to the products (and to the raw materials). For the energy companies, instead of energy use, the production is decomposed.

Decomposition of energy use in industrial companies

The simplest master equation of energy use defines energy use (EN) as a result of two factors/drivers; energy intensity, and the physical amount (PROD). Regarding Equation (7) in the previous chapter, by choosing ES=EN, and X_1=PROD, we get

$$EN = \frac{EN}{PROD} \times PROD \tag{11a}$$

Data of the amount of production in physical units (in tonnes, litres, m^3, etc.) is well available in the reports provided by the case companies. The amount of production is usually available in monetary units too in annual reports, but here we are interested in physical units.

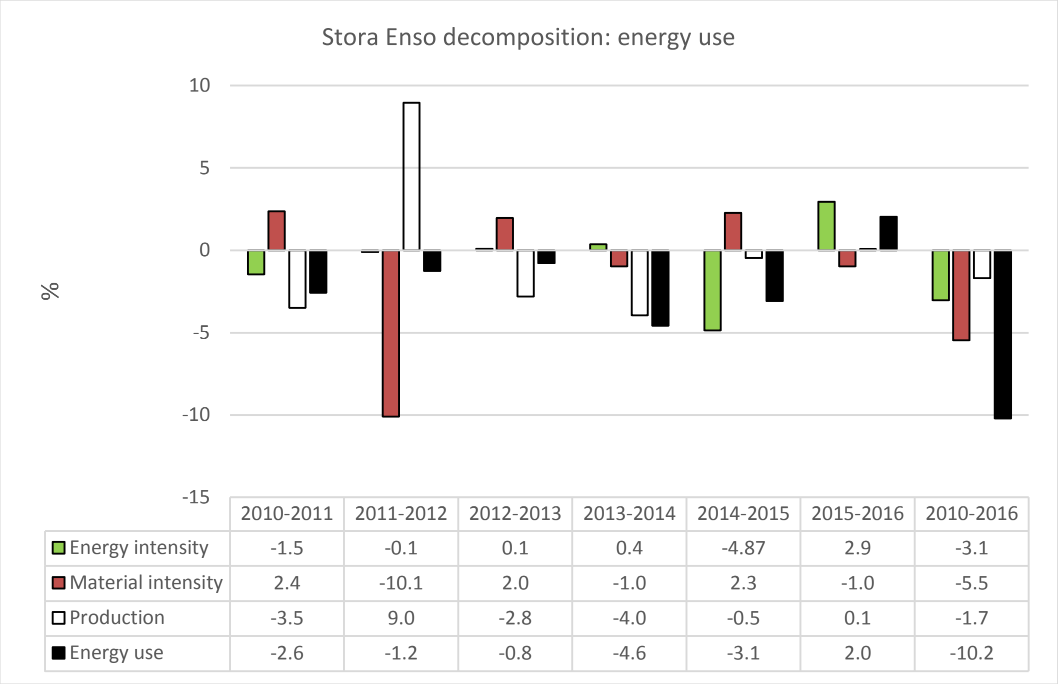
Furthermore, the amount of raw materials (RM) can be chained to the master equation in order to identify three factors/drivers of energy use in the companies: energy intensity (EN/PROD), material efficiency (PROD/RM) and the amount of raw materials (RM):

$$EN = \frac{EN}{RM} \times \frac{RM}{PROD} \times PROD \tag{11b}$$

Both industrial case companies have more than one product, and they use also more than one energy carrier, so aggregation is needed when we want to analyse a company as a whole. We can use a selected major energy carrier, or a selected part of the production, but these should be done only with good arguments in a specific case. In Equations (11a) and (11b), EN is energy use; RM is amount of used raw material(s); PROD is amount of production in physical units. The data can be aggregated, or it can deal with a specific production process or product, if corresponding data is available. The analysis can be carried out also for a specific energy carrier, but data on production/products and raw materials is usually not available.

The only industrial case company with sufficient data for the analysis of equation (11b) for the whole company is Stora Enso. Figure 4 shows that Stora Enso has decreased energy consumption (electricity and fuels, including wood-based fuel used also as raw material in the pulping process) during most of the years in the period 2010-2016, and the most important drivers have been material and energy intensities; i.e. the company has used wood and energy in a more efficient way. The period 2011-2012 is interesting, energy use has slightly decreased due so decreasing material intensity despite of 9 % increase in production measured in tonnes of paper, cardboard and market pulp.

Publicly available data from the other industrial case company, Celsa Barcelona, does not allow this analysis. Data on energy consumption, production and raw materials is not available at corresponding levels (cf. the company description above). Analysis based on equation 11a is possible but it has not been made.



	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2010-2016
🟩 Energy intensity	-1.5	-0.1	0.1	0.4	-4.87	2.9	-3.1
🟥 Material intensity	2.4	-10.1	2.0	-1.0	2.3	-1.0	-5.5
☐ Production	-3.5	9.0	-2.8	-4.0	-0.5	0.1	-1.7
■ Energy use	-2.6	-1.2	-0.8	-4.6	-3.1	2.0	-10.2

Figure 4. Decomposition of change in energy use (total energy consumption), Stora Enso 2010-2016. Variables of Equation (11b): EN=total energy consumption, PROD=paper, cardboard and market pulp, RM=wood use.

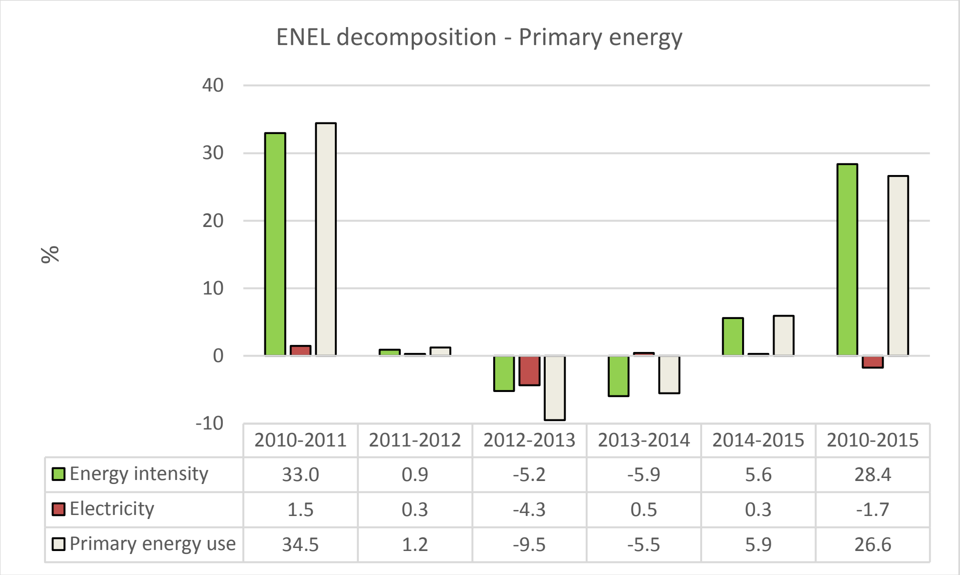
Decomposition of primary energy consumption in energy companies

A basic two-factor master equation of raw material consumption for an energy company can be written as follows (Equation 12). Regarding Equation (7) above, the first choices are in this case ES=RM, and X_1=PROD:

$$RM = \frac{RM}{PROD} \times PROD \tag{12}$$

For industrial companies, this decomposition is not relevant from the perspective of energy efficiency so it is carried out for energy companies only. In an energy company, RM (raw material) refers to primary energy sources and PROD (production) refers to produced energy carriers, so the driver RM/PROD describes the efficiency of the production process where energy carriers (PROD) are produced from primary energy sources (RM). Here the empirical part is easy if a company uses fuel combustion technologies only, but the use of other primary energy sources such as nuclear, solar, wind, or geothermal, is problematic because the “real” primary energy is difficult to measure. In national energy statistics, this problem has been eluded by using pre-defined coefficients for calculating the corresponding amount of primary energy from the amount of produced electricity. However, the driver RM/PROD resembles a macro level driver TPES/FEC which describes the efficiency of the entire energy transformation system (TPES is total primary energy supply and FEC is final energy consumption) and has exactly the same problems (see EUFORIE WP2 deliverable D2.1).

Figure 5 presents the results of decomposing primary energy use of ENEL by using Equation (12). The high increase of primary energy use in 2010-2011(and in 2010-2015) is due to the lack of 2010 data for uranium. Annual changes in energy intensity of electricity production mostly explain the annual changes in primary energy use.

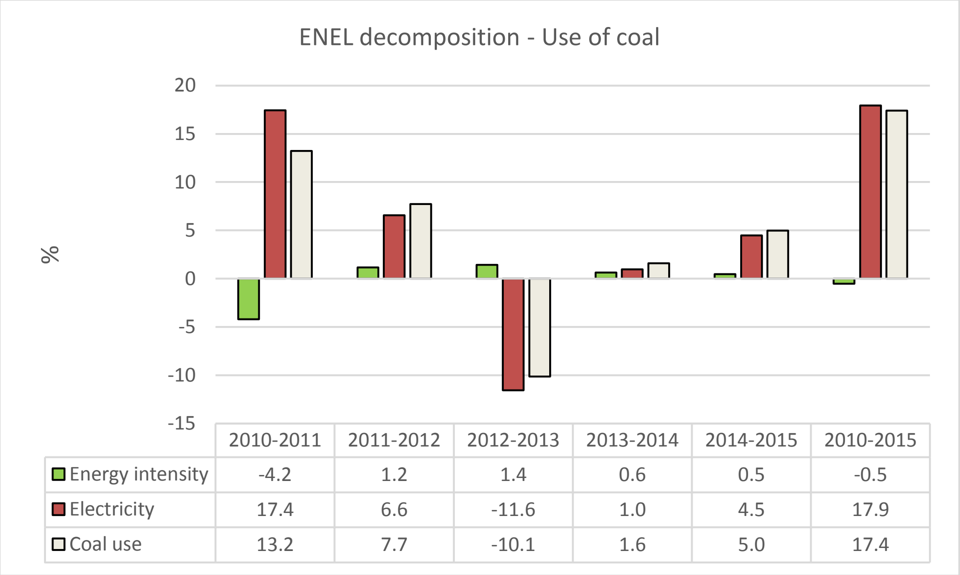


	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2010-2015
🟩 Energy intensity	33.0	0.9	-5.2	-5.9	5.6	28.4
🟥 Electricity	1.5	0.3	-4.3	0.5	0.3	-1.7
☐ Primary energy use	34.5	1.2	-9.5	-5.5	5.9	26.6

Figure 5. Decomposition of change in raw material (total primary energy) consumption for electricity production), ENEL, 2010-2015. Variables of Equation (12): RM=total primary energy consumption, PROD=total electricity production.

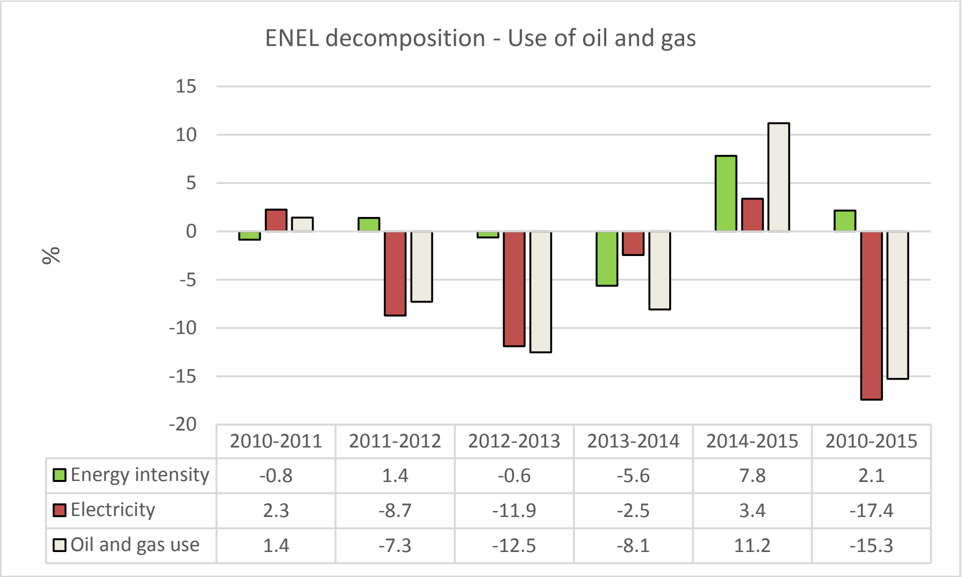
Figures 6-11 present the same decomposition for different primary energy sources used by ENEL: coal (Figure 6), oil and gas (Figure 7), nuclear (Figure 8), aggregated renewables (Figure 9), and two examples of renewables, geothermal (Figure 10) and biomass (Figure 11).

Changes in primary energy consumption are mostly affected by changes in electricity production, changes in intensity plays usually a minor role especially in the cases of fossil fuels (Figures 6 and 7).



	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2010-2015
🟩 Energy intensity	-4.2	1.2	1.4	0.6	0.5	-0.5
🟥 Electricity	17.4	6.6	-11.6	1.0	4.5	17.9
☐ Coal use	13.2	7.7	-10.1	1.6	5.0	17.4

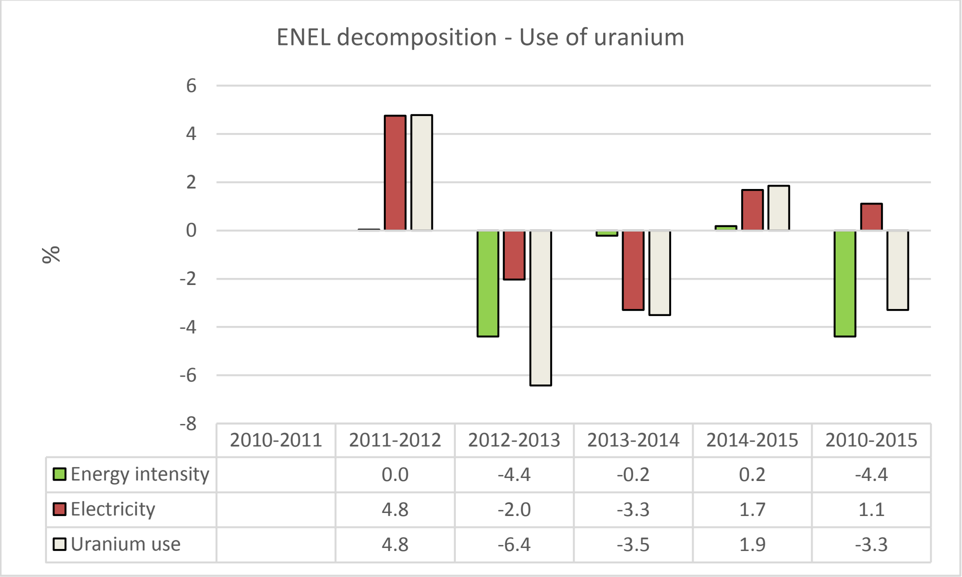
Figure 6. Decomposition of change in raw material (coal) consumption for electricity production, ENEL 2010-2015. Variables of Equation (12): RM=coal consumption, PROD=electricity produced by coal.



	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2010-2015
🟩 Energy intensity	-0.8	1.4	-0.6	-5.6	7.8	2.1
🟥 Electricity	2.3	-8.7	-11.9	-2.5	3.4	-17.4
☐ Oil and gas use	1.4	-7.3	-12.5	-8.1	11.2	-15.3

Figure 7. Decomposition of raw material (gas and oil) for electricity production, ENEL 2010-2015. Variables of Equation (12): RM=gas and oil consumption, PROD=electricity produced by gas and oil.

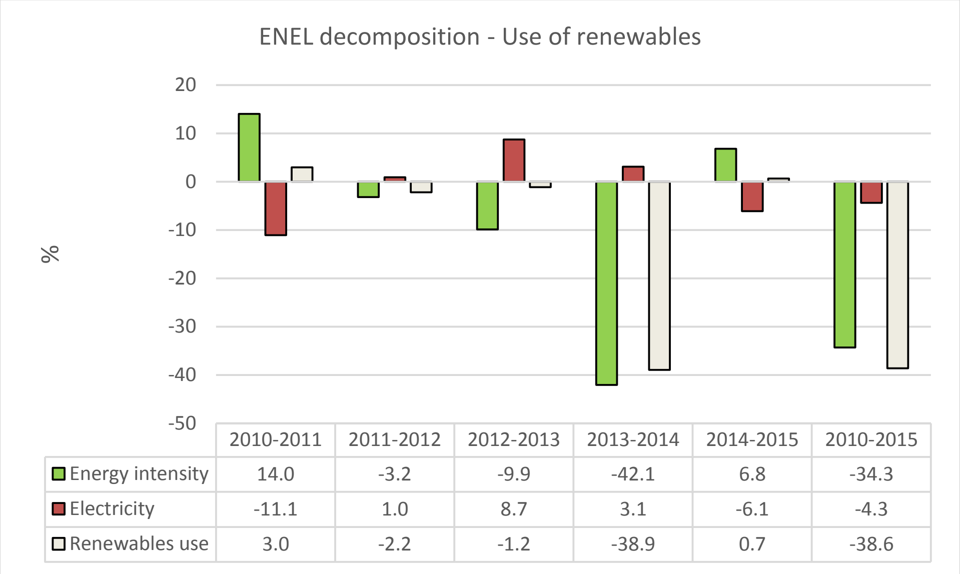
In the case of uranium (Figure 8), change in electricity production also explains change in uranium consumption but in 2012-2013 there seems to be an improvement in the efficiency of nuclear power production.



	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2010-2015
🟩 Energy intensity		0.0	-4.4	-0.2	0.2	-4.4
🟥 Electricity		4.8	-2.0	-3.3	1.7	1.1
☐ Uranium use		4.8	-6.4	-3.5	1.9	-3.3

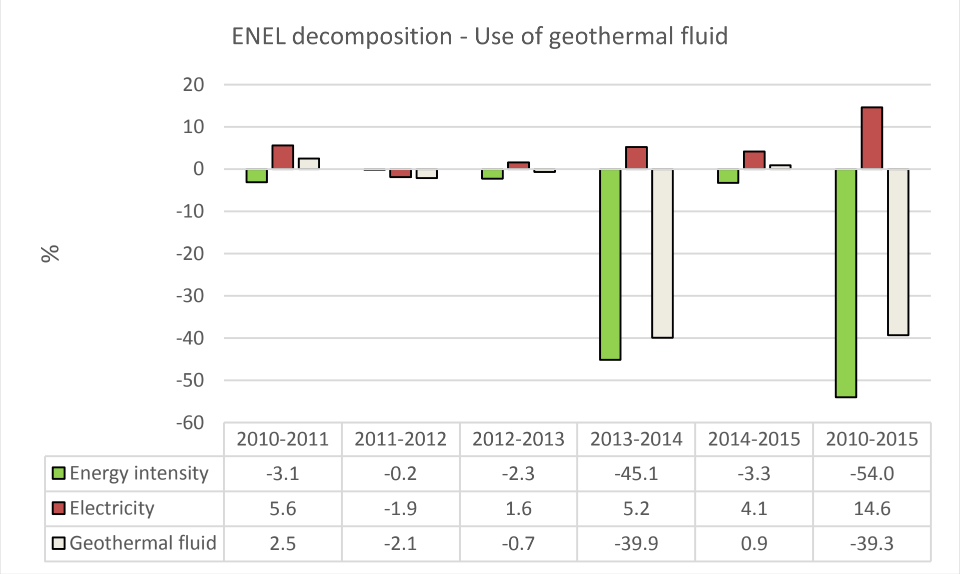
Figure 8. Decomposition of raw material (uranium) consumption for electricity production, ENEL 2010-2015. Variables of Equation (12): RM=uranium consumption, PROD=electricity production by nuclear.

In the case of aggregated renewables (Figure 9), annual effects of energy intensity to electricity production are larger than in the case of the fossil fuels (Figures 6, 7 and 8). This is difficult to explain, but a significant drop in the use of renewables in 2013-2014 (Figure 9) is due to decrease in the use of geothermal energy (Figure 10). According to the data available in the ENEL public reports, the share of geothermal energy is more that 90 % of the total use of renewable primary energy sources.



	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2010-2015
🟩 Energy intensity	14.0	-3.2	-9.9	-42.1	6.8	-34.3
🟥 Electricity	-11.1	1.0	8.7	3.1	-6.1	-4.3
☐ Renewables use	3.0	-2.2	-1.2	-38.9	0.7	-38.6

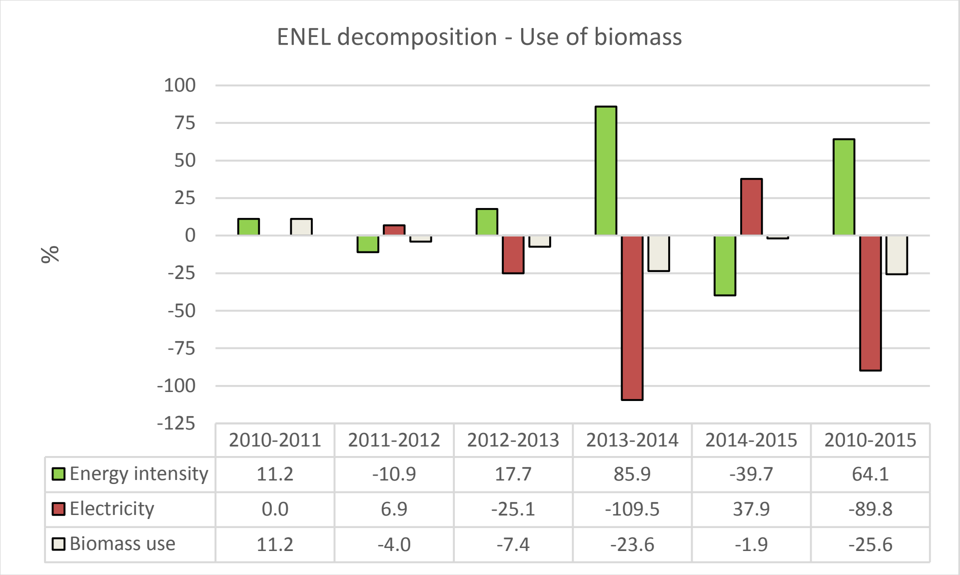
Figure 9. Decomposition of raw material (renewables) for electricity production, ENEL 2010-2015. Variables of Equation (12): RM=total renewables consumption, PROD=electricity production by renewables.



	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2010-2015
🟩 Energy intensity	-3.1	-0.2	-2.3	-45.1	-3.3	-54.0
🟥 Electricity	5.6	-1.9	1.6	5.2	4.1	14.6
☐ Geothermal fluid	2.5	-2.1	-0.7	-39.9	0.9	-39.3

Figure 10. Decomposition of raw material (geothermal fluid) for electricity production, ENEL 2010-2015. Variables of Equation (12): RM=geothermal fluid, PROD=electricity production by geothermal.

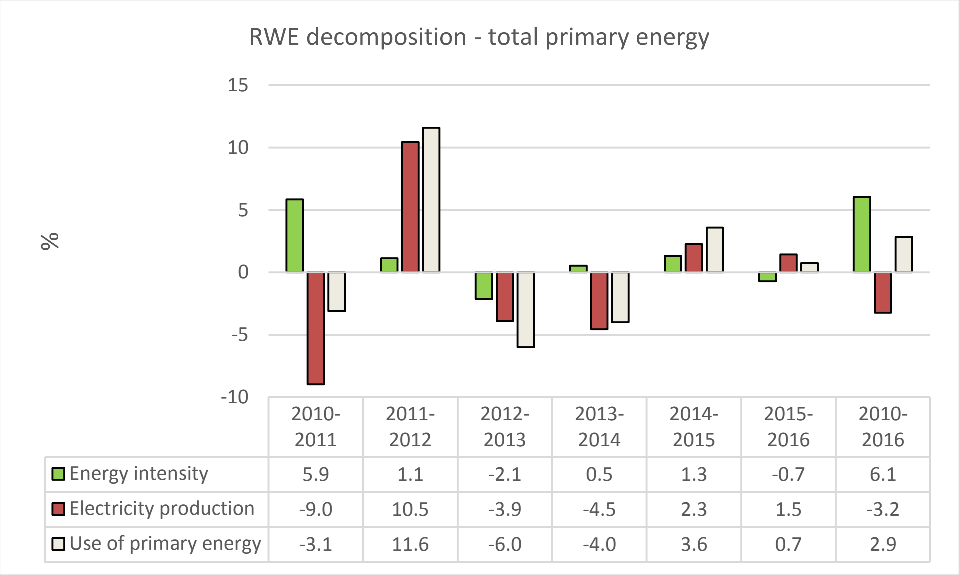
In Figure 11, the decomposition result of biomass use in ENEL for the year 2013-2014 draws attention. it must be kept in mind that only the total change in the use of biomass, which is decomposed into the effects of two drivers (energy intensity and electricity production). If the use of biomass decreases by 24 % and as a result of decomposition the biomass/electricity intensity ratio increases it by 86 %, then the decreasing effect must be over 100 % (for mathematical reasons). The point is that the change (decrease) in electricity production influences more to the change (decrease) in the use of biomass than the change (decrease) in the energy intensity of electricity production from biomass. However, change in the use of biomass is an observation from the data, but changes in intensity and electricity production are mathematical results of decomposition (cf. Figures 2 and 3 above).



	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2010-2015
🟩 Energy intensity	11.2	-10.9	17.7	85.9	-39.7	64.1
🟥 Electricity	0.0	6.9	-25.1	-109.5	37.9	-89.8
☐ Biomass use	11.2	-4.0	-7.4	-23.6	-1.9	-25.6

Figure 11. Decomposition of raw material (biomass) for electricity production, ENEL 2010-2015. Variables of Equation (12): RM=biomass consumption, PROD=electricity production by biomass.

Figures 12-17 present the results of similar decomposition analyses for RWE. Analysis presented in Figure 12 decomposes total primary use into the effects of energy intensity and electricity production and shows quite similarly than in the case of ENEL, in RWE changing amount of total produced electricity explains the change in primary energy use more than the change in primary energy intensity of electricity production. In practical terms, the results can be interpreted via change in the primary energy mix: increasing effect of changing intensity means using more "inefficient" energy sources, o increasing use of power plants with lower thermal efficiency, and perhaps a different mix of fuels in the combustion processes. It is also possible that the use of "efficient" energy sources such as wind, solar and hydro has relatively increased. In ENEL reports, primary energy data is given in Terajoules. Probably normal practices applied in IEA and Eurostat energy statistics have been applied (electricity produced by nuclear is calculated as primary energy by multiplying it by a coefficient 3, electricity produced by geothermal is calculated as primary energy by multiplying it by a coefficient 10, and electricity produced by hydro, wind and solar are calculated As primary energy by multiplying it with a coefficient 1).

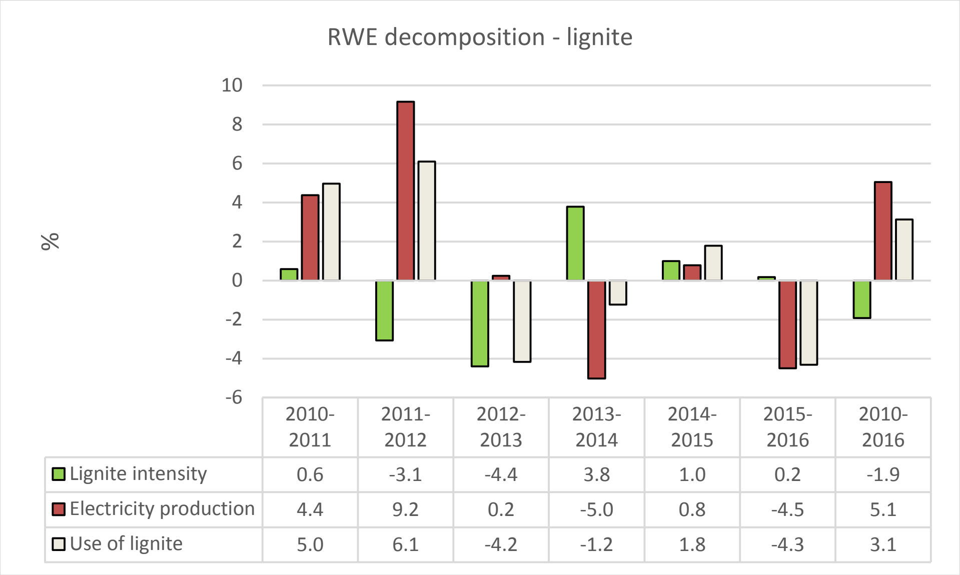


	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2010-2016
🟩 Energy intensity	5.9	1.1	-2.1	0.5	1.3	-0.7	6.1
🟥 Electricity production	-9.0	10.5	-3.9	-4.5	2.3	1.5	-3.2
☐ Use of primary energy	-3.1	11.6	-6.0	-4.0	3.6	0.7	2.9

Figure 12. Decomposition of raw material (total primary energy) for electricity production, RWE 2010-2016. Variables of Equation (12): RM=total primary energy consumption, PROD=total electricity production.

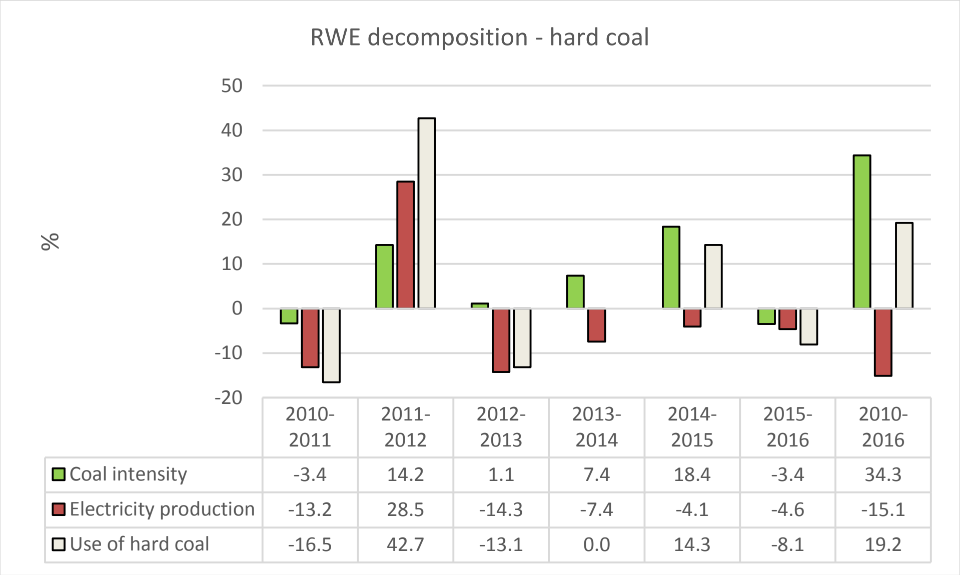
Figures 13-15 show the results from similar decomposition analyses for the use of fossil fuels in RWE: lignite (Figure 13), hard coal (Figure 14) and natural gas (Figure 15). Annual change in the use of these primary energy sources is explained by change in energy intensity of production and change in the amount of electricity produced from the corresponding fossil fuel.

In the cases of individual primary energy sources, change in energy intensity of electricity production explains the change in primary energy use more than in the case of decomposed total primary energy use. In the case of lignite (Figure 13) and natural gas (Figure 15), change in energy intensity has mostly decreases primary energy use. In the case of hard coal, change in energy intensity has more often had an increasing effect to primary energy use, which means that there has not been any development from the perspective of energy efficiency in the use of hard coal in electricity production.



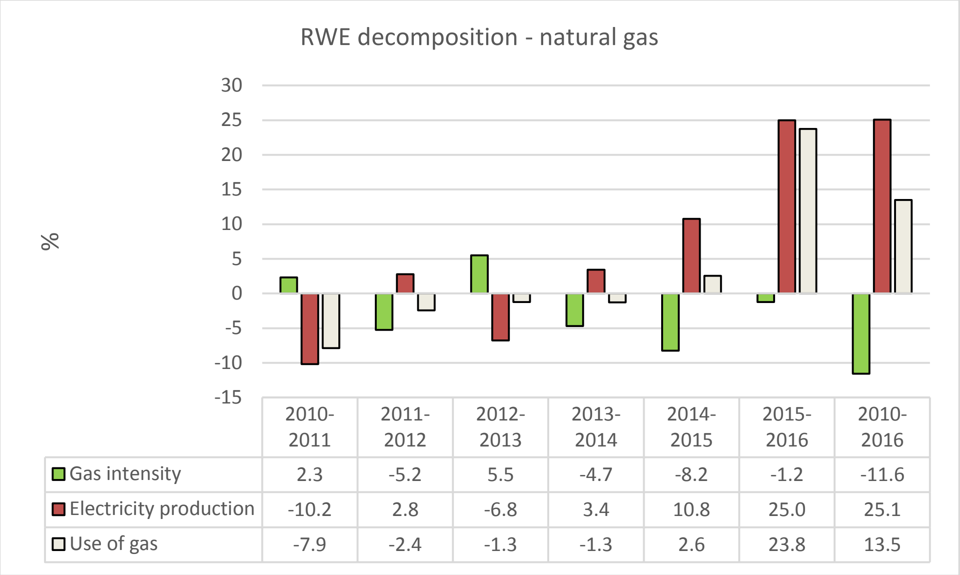
	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2010-2016
🟩 Lignite intensity	0.6	-3.1	-4.4	3.8	1.0	0.2	-1.9
🟥 Electricity production	4.4	9.2	0.2	-5.0	0.8	-4.5	5.1
☐ Use of lignite	5.0	6.1	-4.2	-1.2	1.8	-4.3	3.1

Figure 13. Decomposition of raw material (lignite) for electricity production, RWE 2010-2016. Variables of Equation (12): RM=lignite consumption, PROD=electricity production by lignite.



	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2010-2016
🟩 Coal intensity	-3.4	14.2	1.1	7.4	18.4	-3.4	34.3
🟥 Electricity production	-13.2	28.5	-14.3	-7.4	-4.1	-4.6	-15.1
☐ Use of hard coal	-16.5	42.7	-13.1	0.0	14.3	-8.1	19.2

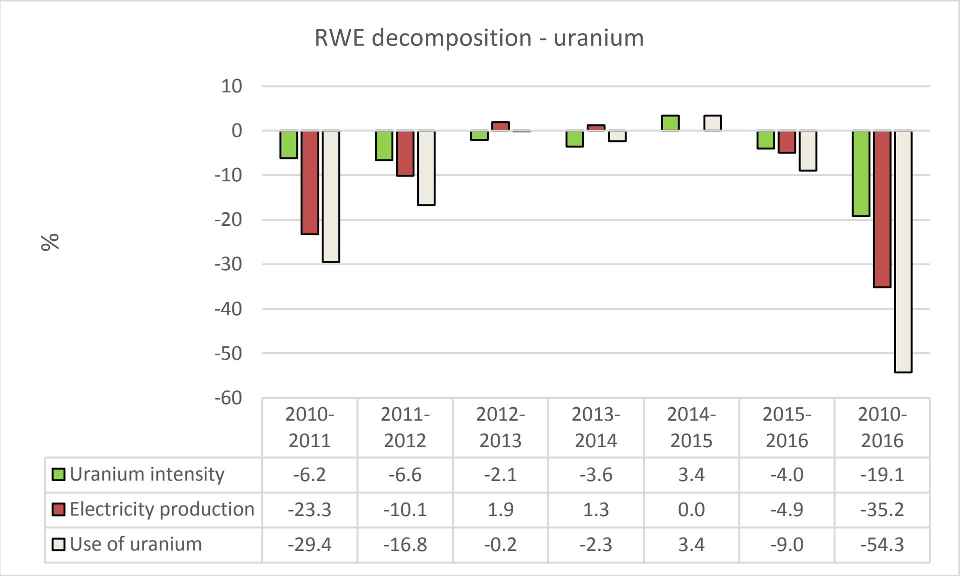
Figure 14. Decomposition of raw material (hard coal) for electricity production, RWE 2010-2016. Variables of Equation (12): RM=hard coal consumption, PROD=electricity produced by hard coal.



	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2010-2016
🟩 Gas intensity	2.3	-5.2	5.5	-4.7	-8.2	-1.2	-11.6
🟥 Electricity production	-10.2	2.8	-6.8	3.4	10.8	25.0	25.1
⬜ Use of gas	-7.9	-2.4	-1.3	-1.3	2.6	23.8	13.5

Figure 15. Decomposition of raw material (natural gas) for electricity production, RWE 2010-2016. Variables of Equation (12): RM=natural gas consumption, PROD=electricity produced by gas.

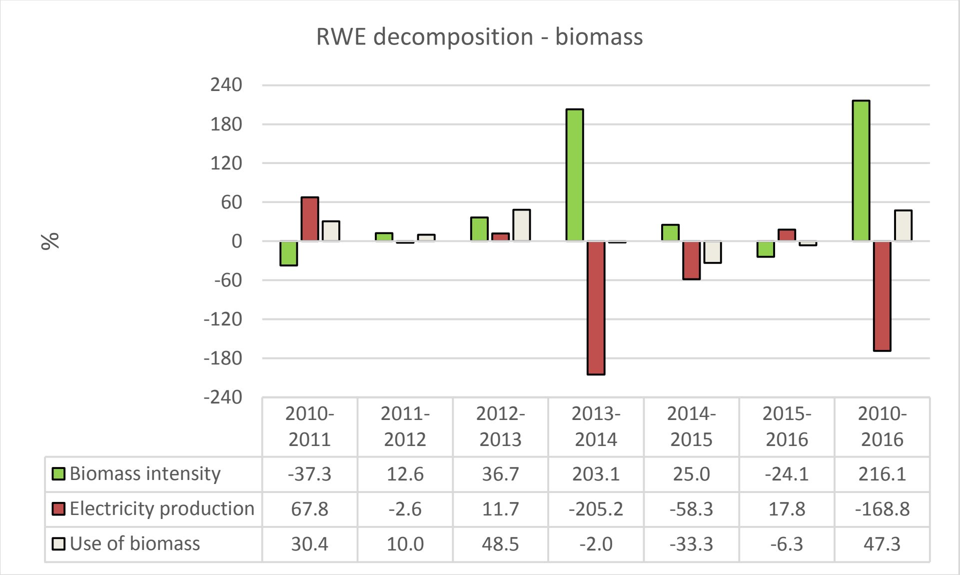
Figure 16 shows the results from decomposition analysis of uranium use in the case of RWE. The uranium intensity of nuclear electricity production has had a decreasing effect to uranium use during the studied period 2010-2016. A similar result came from a corresponding decomposition in the case of ENEL. However, in RWE this has happened almost annually while in ENEL it was for one of the incremental decompositions only.



	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2010-2016
🟩 Uranium intensity	-6.2	-6.6	-2.1	-3.6	3.4	-4.0	-19.1
🟥 Electricity production	-23.3	-10.1	1.9	1.3	0.0	-4.9	-35.2
⬜ Use of uranium	-29.4	-16.8	-0.2	-2.3	3.4	-9.0	-54.3

Figure 16. Decomposition of raw material (uranium) for electricity production, RWE 2010-2016. Variables of Equation (12): RM=uranium consumption, PROD=electricity produced by nuclear.

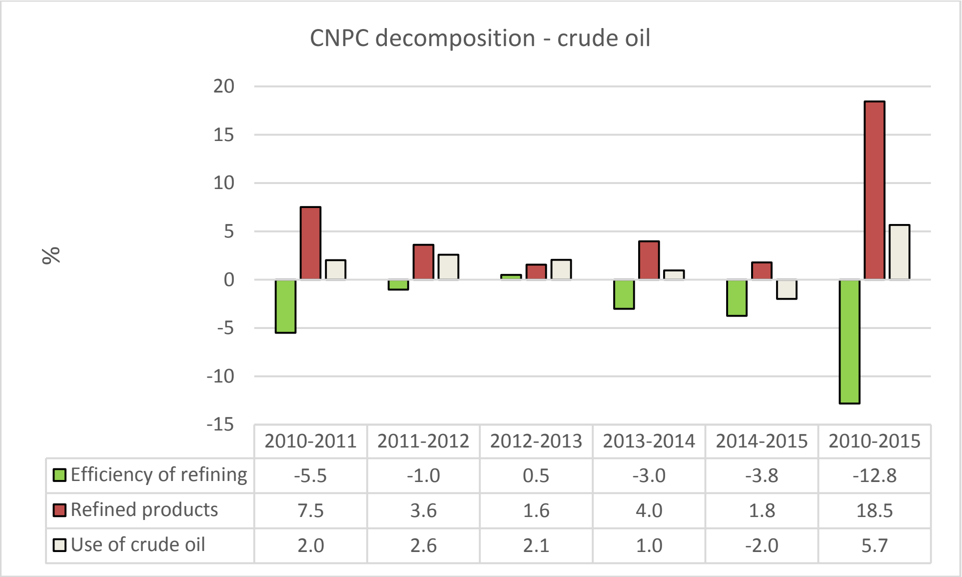
Figure 17 presents the results from decomposition analysis of biomass use in RWE. There are large annual variation in the use of biomass, so the decomposed effect are large too (see what was said about biomass decomposition in the case of ENEL above). In 2013-2014, electricity production from biomass dropped by 77 % while the use of biomass decreased only 2 % according to the RWE online database. This explains the extremely large effects in 2013-2014, which strongly influence the effects during the whole studied period 2010-2016 (Figure 17) in incremental decomposition analysis the effects for a longer time period are calculated by summing the corresponding annual effects.



	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2010-2016
🟩 Biomass intensity	-37.3	12.6	36.7	203.1	25.0	-24.1	216.1
🟥 Electricity production	67.8	-2.6	11.7	-205.2	-58.3	17.8	-168.8
☐ Use of biomass	30.4	10.0	48.5	-2.0	-33.3	-6.3	47.3

Figure 17. Decomposition of raw material (biomass) for electricity production, RWE 2010-2016. Variables of Equation (12): RM=biomass consumption, PROD=electricity produced by biomass.

Figure 18 shows the results from decomposition analysis of crude oil in the case of CNPC. The company is different from the other energy companies selected to this study (ENEL and RWE), because the data suitable for the decomposition analysis in this chapter deals with oil refinery instead of electricity production from primary energy sources. The clear result is that the intensity of CNPC's refining process has decreased the use of crude oil, but the increased amount of refined oil products has caused a slight increase in the use of crude oil (Figure 18). Thus, energy efficiency of CNPC's oil refining process has improved during the studied period 2010-2015, but despite that, the use of crude oil has increased due to increased amount of refined oil products.



	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2010-2015
🟩 Efficiency of refining	-5.5	-1.0	0.5	-3.0	-3.8	-12.8
🟥 Refined products	7.5	3.6	1.6	4.0	1.8	18.5
☐ Use of crude oil	2.0	2.6	2.1	1.0	-2.0	5.7

Figure 18. Decomposition of raw material (crude oil) for production of refined oil products, CNPC 2010-2015. Variables of Equation (12): RM=crude oil consumption, PROD=total production of refined fuels.

Decomposition of environmental impacts

Because reducing environmental impacts is one of the major policy targets related to energy efficiency, it is reasonable to introduce a Master Equation for environmental impacts of companies. In the following, a Master Equations for industrial companies and energy companies will be presented.

In Equation (7) above, the variable which is decomposed into the effects of other variables, is marked with ES because the background of the ASA approach is in sustainability evaluation, and the criterion for environmental sustainability is that *environmental stress* (ES) should not increase (cf. Kaivo-oja et al 2001a; 2001b). The same holds with all environmental indicators, and they are marked as ES in the following.

Environmental impacts of industrial companies

A typical indicator for environmental impacts is carbon dioxide emissions (CO_2). When necessary, it can be replaced by other indicators, which are available in the companies' environmental reporting. Because CO_2 emissions are mostly caused by fossil fuel combustion, a simple Master Equation uses energy use (EN) as the first driver and regarding Equation (7), the first choices are ES=ES and X_1=EN (Equation 13a):

$$ES = \frac{ES}{EN} \times EN \tag{13a}$$

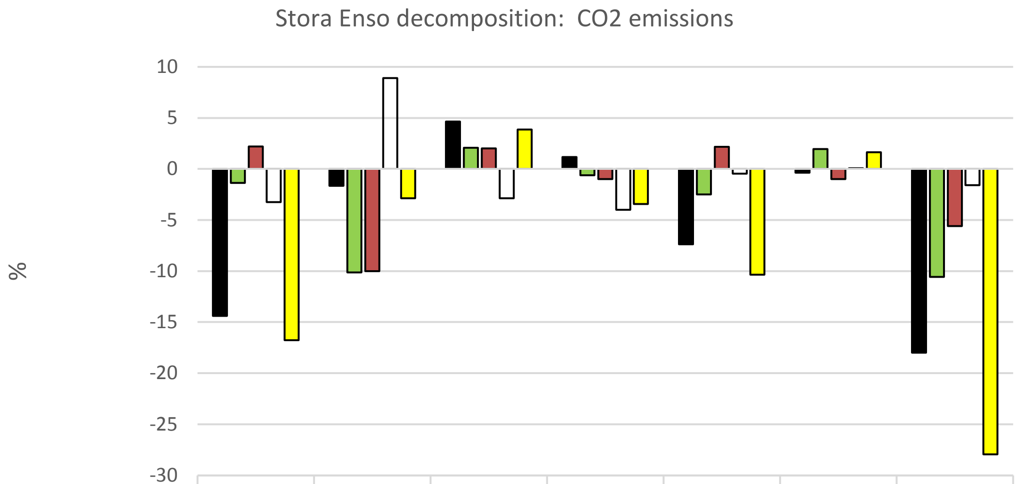
Likewise in decomposition of energy use, also environmental stress is driven by energy intensity, which is an inverse of energy efficiency. Amount of used raw materials can be chained to the equation by choosing ES=ES, X_1=EN and X_2=RM (Equation 13b):

$$ES = \frac{ES}{EN} \times \frac{EN}{RM} \times RM \tag{13b}$$

If we chain production into Equation (14b) and choose ES=ES, X_1=EN, X_2=RM, and X_3=PROD, we get a four-factor Equation (Equation 14c). The drivers of environmental stress then include environmental intensity of energy use (ES/EN), energy intensity of material use (EN/RM), material intensity of production (RM/PROD), and the amount of production, PROD (Equation 13c):

$$ES = \frac{ES}{EN} \times \frac{EN}{RM} \times \frac{RM}{PROD} \times PROD \tag{13c}$$

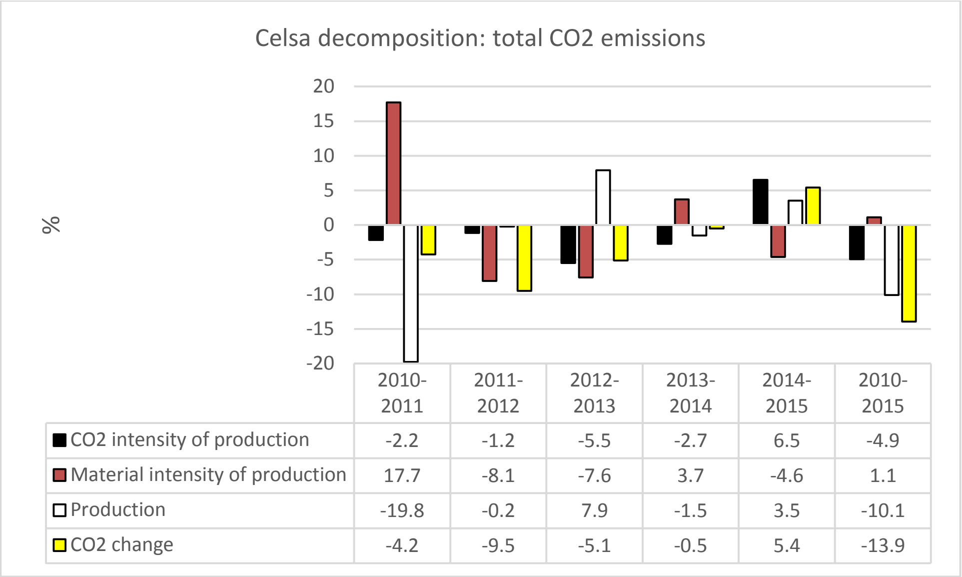
Figure 19 shows the results from a decomposition analysis of forest company Stora Enso's carbon dioxide emissions. Total CO_2 emissions have decreased during 4 out of the 6 studied years, and the change during the whole period 2010-2016 has been a decrease of 28 % from the 2010 level. The largest contribution to this decrease has come from a change in CO_2 intensity of the energy mix, which can be explained by increasing use of bioenergy in the production process. Indirect CO_2 emissions have been excluded from the analysis, so possible change in the production mix of purchased electricity cannot be used as an explanation in this analysis. Other contributing drivers include decreasing energy intensity of the raw material use, and decreasing material intensity of production. The analysis does not include other raw materials than wood; including them might change the contribution of these factors and thus the contribution of change in the amount production of paper, cardboard and market pulp. These product mix included in the analysis does not include wood products and corrugated cardboard, because their amount are not available in tonnes. It is important to keep in mind that choices made in the selection of data usually affect the results.



	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2010-2016
■ CO2 intensity	-14.4	-1.6	4.7	1.2	-7.4	-0.4	-18.0
🟩 Energy intensity	-1.4	-10.1	2.1	-0.6	-2.5	2.0	-10.6
🟥 Material intensity	2.2	-10.0	2.0	-1.0	2.2	-1.0	-5.6
□ Production	-3.2	8.9	-2.9	-4.0	-0.5	0.1	-1.6
🟨 CO2 emissions	-16.8	-2.9	3.9	-3.4	-10.4	1.7	-27.9

Figure 19. Decomposition of environmental impacts (CO_2 emissions), Stora Enso 2010-2016. Variables of Equation (13c): ES=total CO_2 emissions, EN=total energy consumption, RM=wood use, PROD=production of paper, cardboard and market pulp.

Figures 20-24 show decomposition results for the other industrial case company, Celsa Barcelona, a manufacturer of different steel products. The data available for the analysis is very limited, but Figure 20 shows the result of a three-factor decomposition analysis of total CO_2 emissions into the effects of carbon intensity of raw material use, material intensity of production, and the amount of total production. The CO_2 emissions have decreased during the studied period 2010-2015 by 14 %, and the largest decreasing effect has come from the amount of production. Material intensity of production has also contributed to decreasing CO_2 emissions in some of the years, but during the whole period, its increasing effect is smaller than the decreasing effects of energy intensity and amount of production (Figure 20). CO_2 intensity of material use has contributed more than material intensity of production during the whole period 2010-2015.



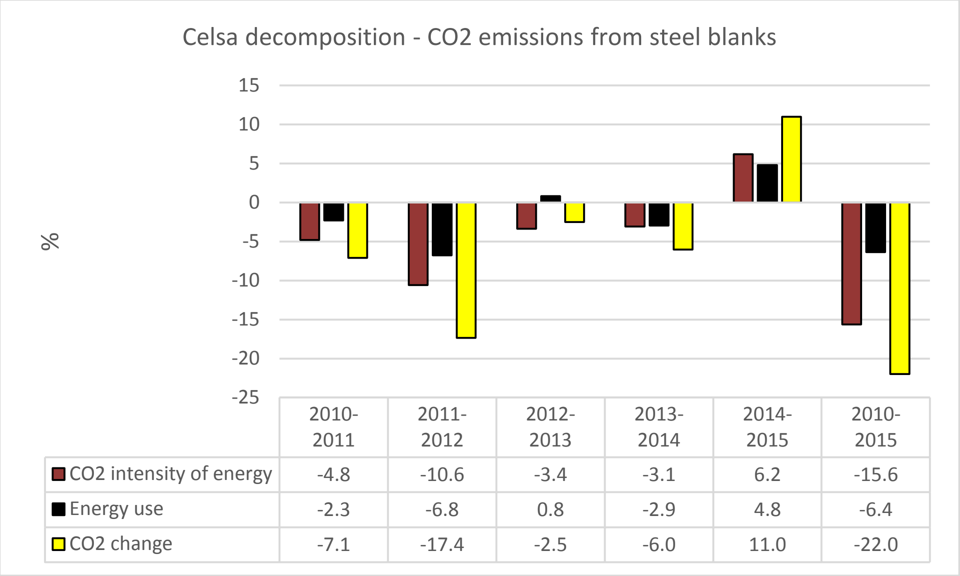
	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2010-2015
■ CO2 intensity of production	-2.2	-1.2	-5.5	-2.7	6.5	-4.9
🟥 Material intensity of production	17.7	-8.1	-7.6	3.7	-4.6	1.1
□ Production	-19.8	-0.2	7.9	-1.5	3.5	-10.1
🟨 CO2 change	-4.2	-9.5	-5.1	-0.5	5.4	-13.9

Figure 20. Decomposition of environmental impacts (CO_2 emissions), Celsa Barcelona, 2010-2015. Variables of Equation (13a): ES=total CO_2 emissions, RM=scrap and steel alloys, PROD=total of manufactured products.

A good thing in Celsa Barcelona's publicly available data is that it enables simple two-factor decomposition analyses at the product level. Figures 21-24 show results from decompositions of CO_2 emissions for four major product groups, steel billets (Figure 21), wires and rods (Figure 22), structural profiles (Figure 23) and steel platen (Figure 24). The decomposed effects include CO_2 intensity of energy and energy use, CO_2 emissions and energy consumption are the only variables where data is available at the level of product groups. Unfortunately, data on the amount of production and raw materials is available at the level of the whole company only so it cannot be used in this analysis.

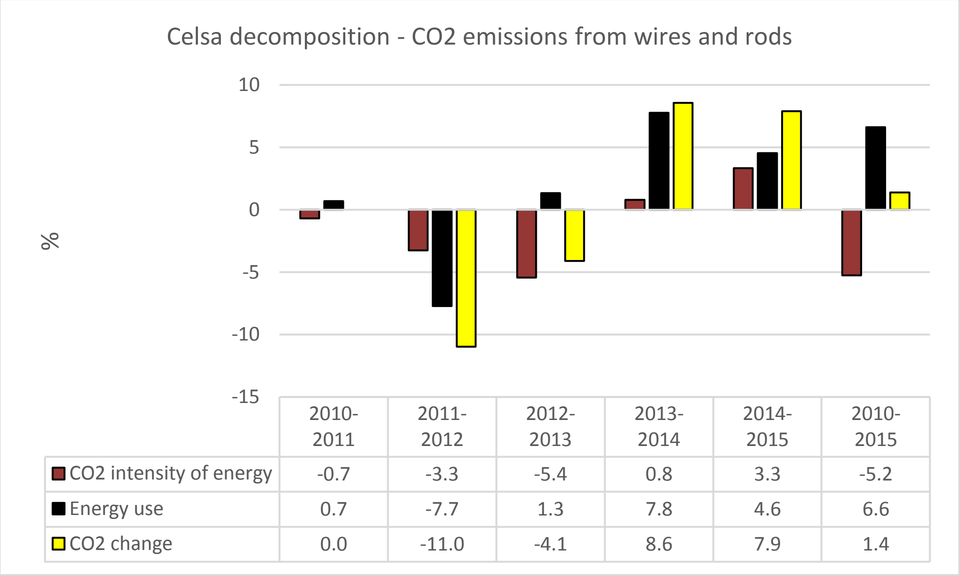
Decrease of CO_2 emissions in steel blank production has been continuous except in 2014-2015, and during the whole studied period 2010-2015 CO_2 emissions have decreased 22 % (Figure 21). Both carbon intensity of energy and energy use have had a decreasing effect on CO_2 emissions during the whole studied period and in three of the five studied annual changes. Although data on the amount of production is not available at the level of product groups, the decomposition result gives a reason to conclude that the production of steel blanks has probably decreased during the studied period (Figure 21, cf. Figure 20).

CO_2 emissions of production of wires and rods has varied during the studied years, first no change, then decreased but then increased (Figure 22). When the whole period 2010-2015 is looked at, CO_2 emissions have slightly increased. This has been mainly due to an increasing effect of energy use in the production process. The effect of CO_2 intensity of energy has been a decreasing one in the two first analysed annual changes and during the whole studied period (Figure 22).



	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2010-2015
🟥 CO2 intensity of energy	-4.8	-10.6	-3.4	-3.1	6.2	-15.6
■ Energy use	-2.3	-6.8	0.8	-2.9	4.8	-6.4
🟨 CO2 change	-7.1	-17.4	-2.5	-6.0	11.0	-22.0

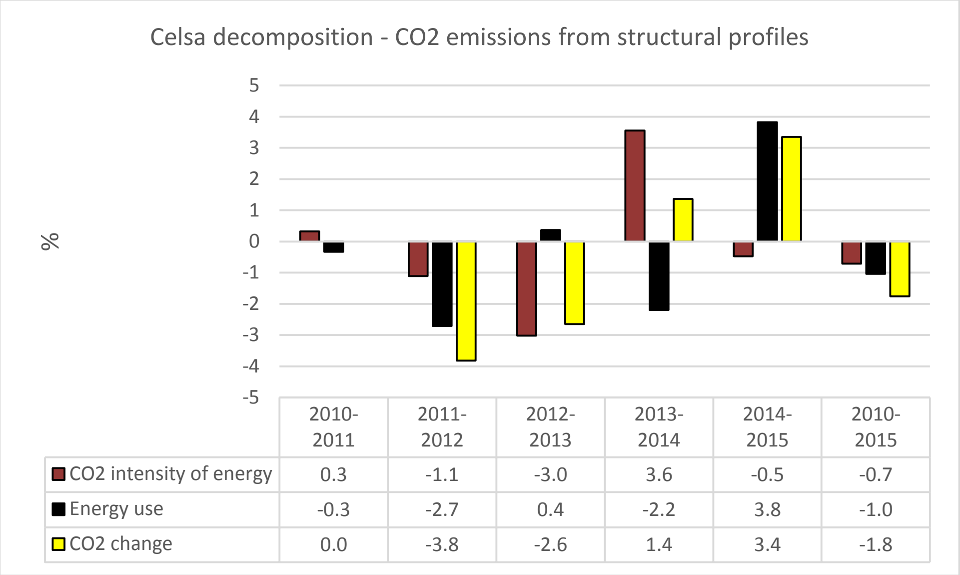
Figure 21. Decomposition of environmental impacts (CO_2 emissions from production of steel blanks), Celsa Barcelona 2010-2015. Variables of Equation (13a): ES=CO_2 emissions from production of steel blanks, EN=energy use index of production of steel blanks.



	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2010-2015
🟥 CO2 intensity of energy	-0.7	-3.3	-5.4	0.8	3.3	-5.2
■ Energy use	0.7	-7.7	1.3	7.8	4.6	6.6
🟨 CO2 change	0.0	-11.0	-4.1	8.6	7.9	1.4

Figure 22. Decomposition of environmental impacts (CO_2 emissions from production of wires and rods), Celsa Barcelona 2010-2015. Variables of Equation (13a): ES=CO_2 emissions from production of wires and rods, EN=energy use index of production of wires and rods.

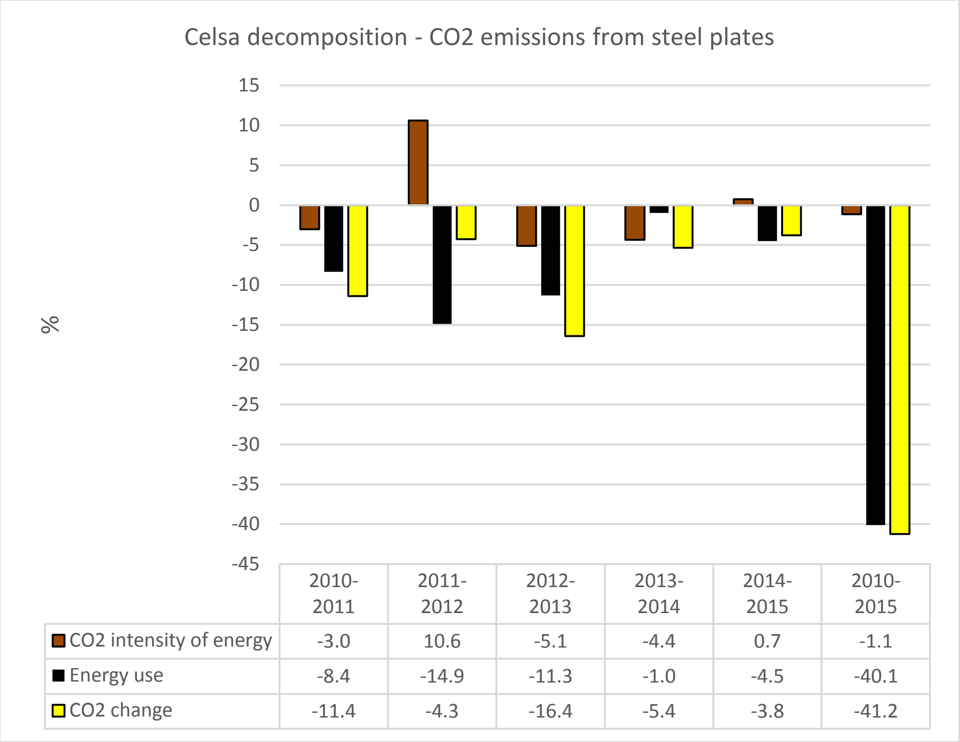
Product group structural profiles shows a varying trend of annual change in CO_2 emissions. First they have decreased and then increased, and during the whole studied period the emissions have slightly decreased (Figure 23). Largest decreasing contribution has come from change in energy use, but the difference between energy use and CO_2 intensity of energy is not large. Both drivers have decreased and increased CO_2 emissions, depending on the annual change analysed.



	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2010-2015
🟥 CO2 intensity of energy	0.3	-1.1	-3.0	3.6	-0.5	-0.7
■ Energy use	-0.3	-2.7	0.4	-2.2	3.8	-1.0
🟨 CO2 change	0.0	-3.8	-2.6	1.4	3.4	-1.8

Figure 23. Decomposition of environmental impacts (CO_2 emissions from production of structural profiles), Celsa Barcelona 2010-2015. Variables of Equation (13a): ES=CO_2 emissions from production of structural profiles, EN=energy use index of production of structural profiles.

The largest decrease in CO_2 emissions has taken place in the Celsa Barcelona's product group steel plates during the studied time period 2010-2015. A significant 41 % decrease during five years can almost totally be explained by decreasing energy use (Figure 24). This gives reason to conclude that the amount of production has also decreased although data of production is not available at the level of product groups (cf. Figure 20). Annually, both drivers, CO_2 intensity of energy and energy use, have had a decreasing effect. The only exception is CO_2 intensity ,which has had an increasing effect in 2011-2012.



	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2010-2015
🟫 CO2 intensity of energy	-3.0	10.6	-5.1	-4.4	0.7	-1.1
■ Energy use	-8.4	-14.9	-11.3	-1.0	-4.5	-40.1
🟨 CO2 change	-11.4	-4.3	-16.4	-5.4	-3.8	-41.2

Figure 24. Decomposition of environmental impacts (CO_2 emissions from production of steel plates), Celsa Barcelona 2010-2015. Variables of Equation (13a): ES=CO_2 emissions from production of steel plates, EN=energy use index of production of steel plates.

Environmental impacts of energy companies

In energy companies, the Master Equation of environmental impacts lacks the variable of energy use because products and raw materials are both energy, so energy efficiency is described best by their relationship. For energy companies, the first choices to Equation (7) are thus the following: ES=ES, and X_1=RM, the latter refers to the amount of used primary energy (Egiation (14a):

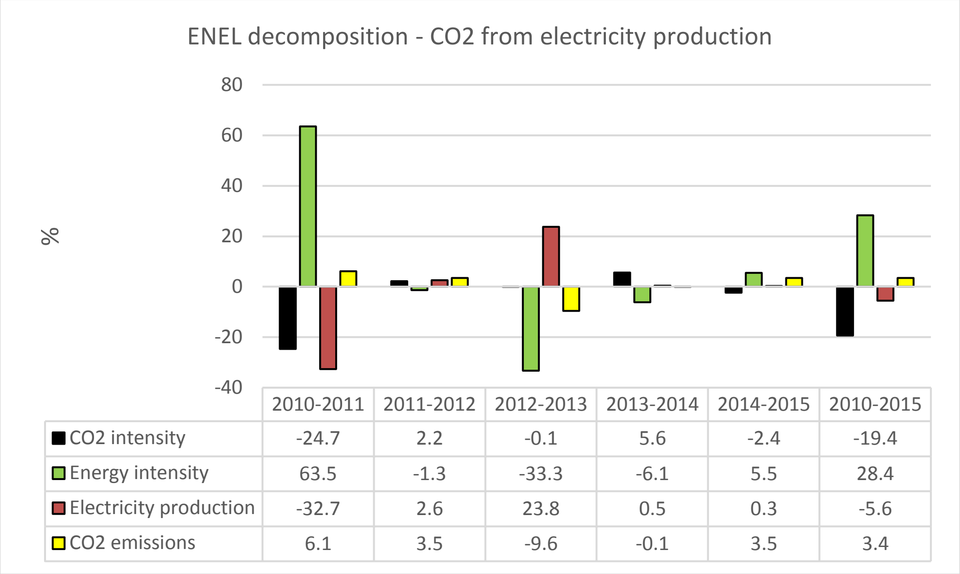
$$ES = \frac{ES}{RM} \times RM \qquad (14a)$$

Energy efficiency can then be identified for energy companies by chaining production, i.e. the amount of produced energy carriers (Equation 14b):

$$ES = \frac{ES}{RM} \times \frac{RM}{PROD} \times PROD \qquad (14b)$$

Thus, the drivers of environmental impacts in energy companies include environmental intensity of primary energy (ES/RM), efficiency of the energy conversion (RM/PROD) and the amount of produced energy carriers (PROD).

Figure 25 shows the results from decomposition analysis of CO_2 emission sin ENEL. The change in CO_2 emissions has been rather small during the studied period 2010-2015. Decreasing effects have come from changes in CO_2 intensity and slightly decreasing amount of electricity production. The effect of changing energy intensity of electricity production is probably a result from changing energy mix, the use of "inefficient" primary energy sources seems to have increased.

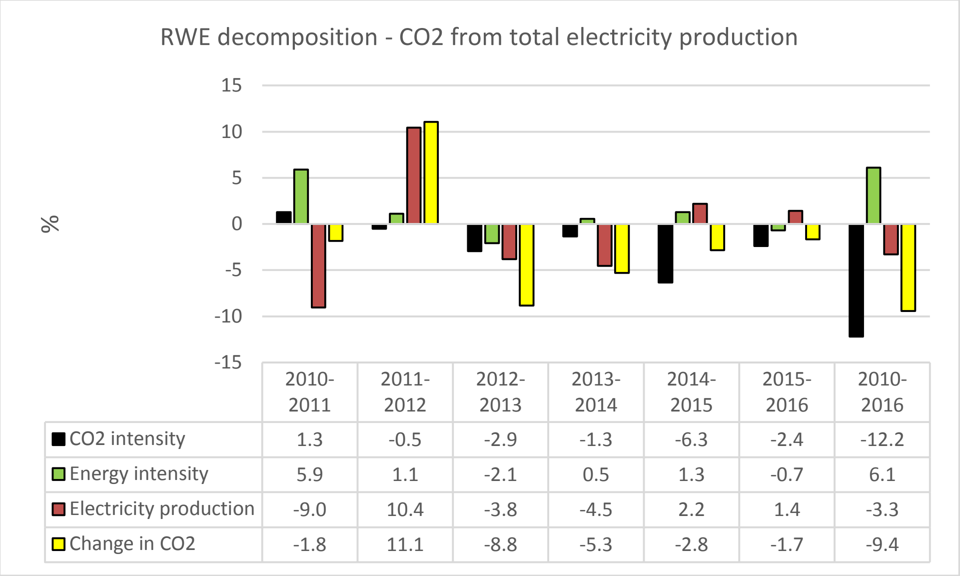


	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2010-2015
⬛ CO2 intensity	-24.7	2.2	-0.1	5.6	-2.4	-19.4
🟩 Energy intensity	63.5	-1.3	-33.3	-6.1	5.5	28.4
🟥 Electricity production	-32.7	2.6	23.8	0.5	0.3	-5.6
🟨 CO2 emissions	6.1	3.5	-9.6	-0.1	3.5	3.4

Figure 25. Decomposition of environmental impacts (CO emissions), ENEL 2010-2015. Variables of Equation (14b): ES=total CO_2 emissions, RM=total primary energy use, PROD=total electricity production.

Figures 26-32 present the results from decomposition analyses of different environmental impacts of electricity production in RWE. The decomposed environmental impacts include total CO_2 emissions (Figure 26), as well as NO_x and SO_2 emissions from three fossil primary energy sources used for electricity production, lignite (Figures 27 and 28), hard coal (Figures 29 and 30), and natural gas (Figures 31 and 32). NO_x emissions and SO_2 emissions have not been decomposed before by using the ASA decomposition technique. Thus, this study includes also another novelty in addition to the fact that ASA decomposition is applied first time to the company level analysis.

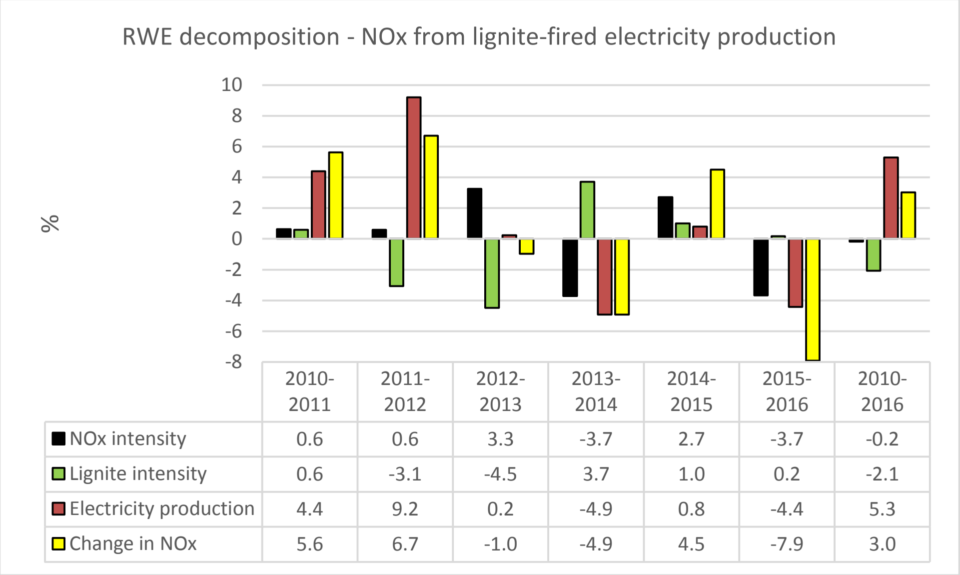
Figure 26 shows that CO_2 intensity of primary energy use for electricity consumption has had a decreasing effect on total CO_2 emissions in RWE during the studied period 2010-2016. The amount of generated electricity naturally contributes to CO_2 emissions, and energy intensity of electricity production has had a slight increasing effect to CO_2 emissions. This is obviously a result of changing energy mix in terms of primary energy sources, which could be assessed by other decomposition techniques which take structural effects into consideration.



	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2010-2016
■ CO2 intensity	1.3	-0.5	-2.9	-1.3	-6.3	-2.4	-12.2
🟩 Energy intensity	5.9	1.1	-2.1	0.5	1.3	-0.7	6.1
🟥 Electricity production	-9.0	10.4	-3.8	-4.5	2.2	1.4	-3.3
🟨 Change in CO2	-1.8	11.1	-8.8	-5.3	-2.8	-1.7	-9.4

Figure 26. Decomposition of environmental impact (CO_2 emissions from electricity production), RWE 2010-2016. Variables of Equation (14b): ES=total CO_2 emissions, RM=total primary energy use, PROD=total electricity production.

Figures 27 and 28 present the results from decomposition of NO_x emissions and SO_2 emissions from the use of lignite for electricity production in RWE. Change in both emissions have varied from year to year, sometimes they are increasing, sometimes decreasing. During the studied period 2010-2016 as a whole, NO_x emissions have decreased by 3 % (Figure 27) and SO_2 emissions by 7 % (Figure 28) from the first year value of corresponding emissions.

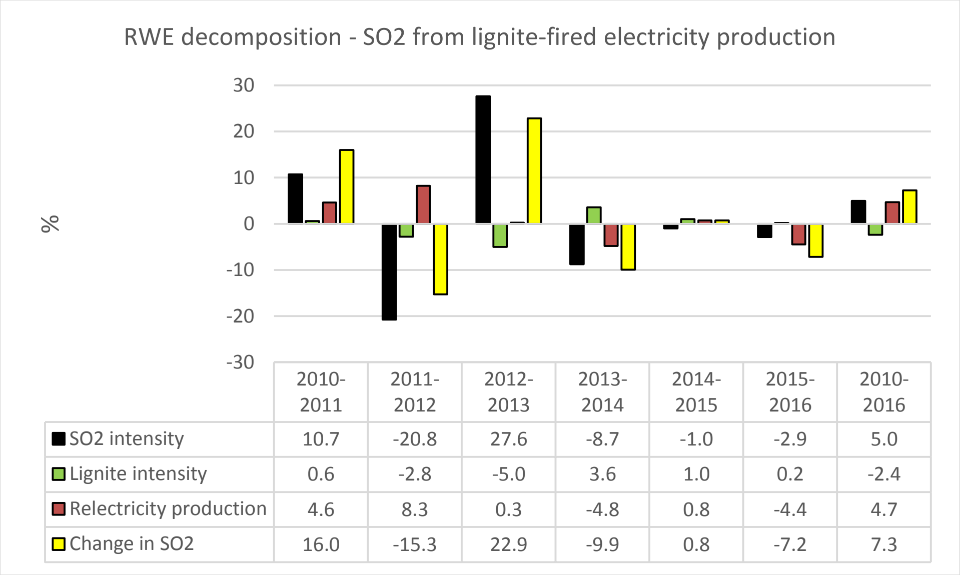


	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2010-2016
■ NOx intensity	0.6	0.6	3.3	-3.7	2.7	-3.7	-0.2
🟩 Lignite intensity	0.6	-3.1	-4.5	3.7	1.0	0.2	-2.1
🟥 Electricity production	4.4	9.2	0.2	-4.9	0.8	-4.4	5.3
🟨 Change in NOx	5.6	6.7	-1.0	-4.9	4.5	-7.9	3.0

Figure 27. Decomposition of environmental impacts (NO_x emissions from lignite use for electricity production), RWE 2010-2016. Variables of Equation (14b): ES=NO_x emissions from lignite, RM=lignite consumption, PROD=electricity production from lignite.

Change in NO_x emissions follows the amount of electricity production, which has the largest increasing or decreasing effects to the change in NO_x emissions (Figure 27). Lignite intensity describes the efficiency of the combustion processes, and NO_x intensity describes the characteristics of the used lignite fuel. Both drivers seem to have decreasing and increasing effects depending on the studied annual change. During the studied period as a whole, both drives have a small decreasing effect to the change of NO_x emissions (Figure 27).

SO_2 emissions of electricity production from lignite have also decreased or increased depending on the studied annual change, and the size of the change is larger than in the case of NO_x emissions, on average (Figure 28). Similarly as above, SO_2 intensity describes the characteristics of the used lignite fuel, and the effect lignite intensity describes the changing overall or average efficiency of the combustion processes in different power plants. Change in SO_2 emissions seems to follow best the change in SO_2 intensity, so the emissions depend quite clearly from the quality of the used lignite fuel in terms of sulphur (S) content. Efficiency of the combustion process has had a small decreasing effect to SO_2 emissions.

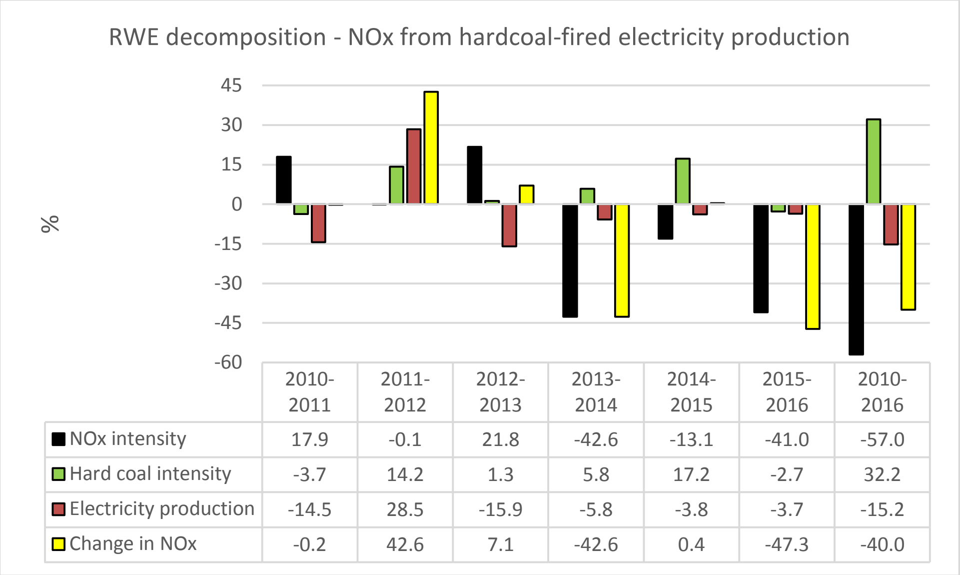


	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2010-2016
■ SO2 intensity	10.7	-20.8	27.6	-8.7	-1.0	-2.9	5.0
🟩 Lignite intensity	0.6	-2.8	-5.0	3.6	1.0	0.2	-2.4
🟥 Relectricity production	4.6	8.3	0.3	-4.8	0.8	-4.4	4.7
🟨 Change in SO2	16.0	-15.3	22.9	-9.9	0.8	-7.2	7.3

Figure 28. Decomposition of environmental impacts (SO_2 emissions from lignite use for electricity production), RWE 2010-2016. Variables of Equation (14b): ES=SO_2 emissions from lignite, PROD=electricity production from lignite, and RM=lignite consumption.

Figures 29 and 30 present the results from decomposition of NO_x emissions and SO_2 emissions from the use of hard coal for electricity production in RWE. During the studied period 2010-2016 as a whole, NO_x emissions have decreased by 40 % (Figure 29) and SO_2 emissions by 39 % (Figure 30) from the first year value of corresponding emissions.

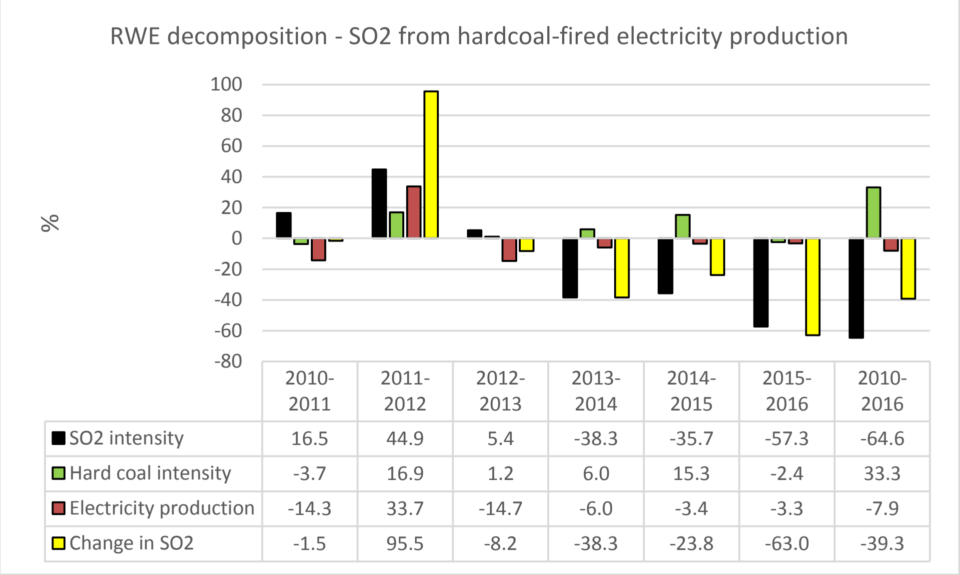
Change in NO_x emissions follows best change in the NO_x intensity of used hard coal fuel, and also the change in the amount of produced electricity. Change in hard coal intensity, which describes a change in efficiency of the combustion process, has surprisingly had an increasing effect to NO_x emissions of hard coal use in RWE.



	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2010-2016
■ NOx intensity	17.9	-0.1	21.8	-42.6	-13.1	-41.0	-57.0
🟩 Hard coal intensity	-3.7	14.2	1.3	5.8	17.2	-2.7	32.2
🟥 Electricity production	-14.5	28.5	-15.9	-5.8	-3.8	-3.7	-15.2
🟨 Change in NOx	-0.2	42.6	7.1	-42.6	0.4	-47.3	-40.0

Figure 29. Decomposition of environmental impacts (NO_x emissions from hard coal use for electricity production), RWE 2010-2016. Variables of Equation (14b): ES=NO_x emissions from hard coal, PROD=electricity production from hard coal, and RM=hard coal consumption.

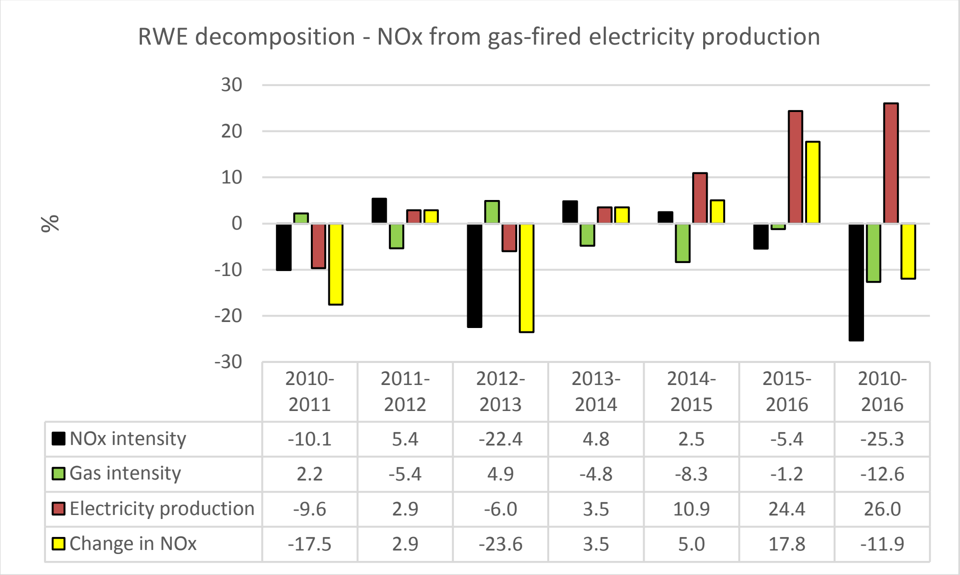
Change in SO_2 emissions seems to follow best the change in SO_2 intensity of the used hard coal fuel (Figure 30), so similarly as in the case of lignite above (Figure 28), the SO_2 emissions depend quite clearly on the quality of the used hard coal fuel in terms of its sulphur (S) content. Efficiency of the combustion processes using hard coal has had an increasing effect to SO_2 emissions, a similar result came out from the decomposition analysis of NO_x emissions too (Figure 29).



	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2010-2016
■ SO2 intensity	16.5	44.9	5.4	-38.3	-35.7	-57.3	-64.6
🟩 Hard coal intensity	-3.7	16.9	1.2	6.0	15.3	-2.4	33.3
🟥 Electricity production	-14.3	33.7	-14.7	-6.0	-3.4	-3.3	-7.9
🟨 Change in SO2	-1.5	95.5	-8.2	-38.3	-23.8	-63.0	-39.3

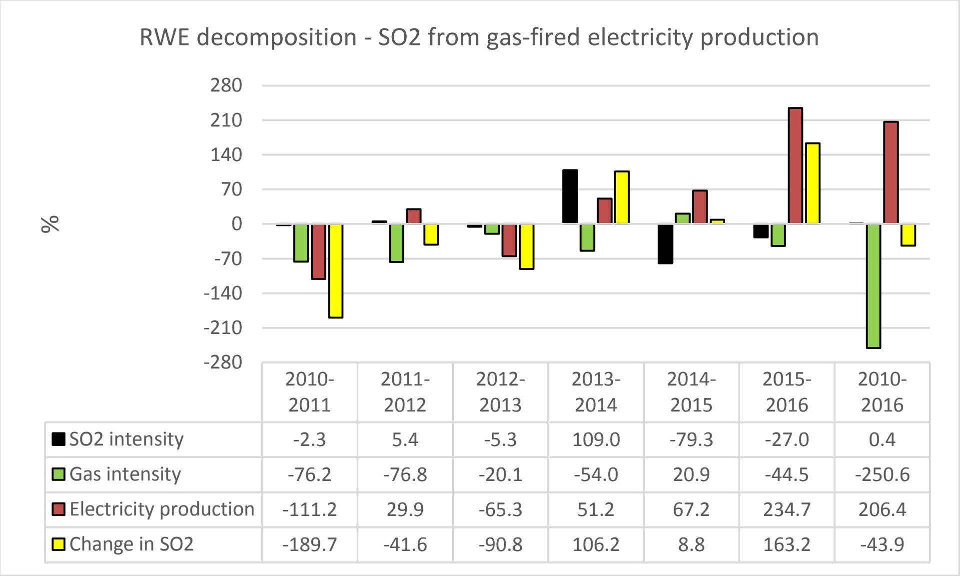
Figure 30. Decomposition of environmental impacts (SO_2 emissions from hard coal use for electricity production), RWE 2010-2016. Variables of Equation (14b): ES=SO_2 emissions from hard coal, PROD=electricity production from hard coal, and RM=hard coal consumption.

Figures 31 and 32 present the results from decomposition of NO_x emissions and SO_2 emissions from the use of natural gas for electricity production in RWE. Change in both emissions have varied from year to year, sometimes they are increasing, sometimes decreasing. During the studied period 2010-2016 as a whole, NO_x emissions have decreased by 12 % (Figure 31) and SO_2 emissions by 44 % (Figure 32) from the 2010 value.



	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2010-2016
■ NOx intensity	-10.1	5.4	-22.4	4.8	2.5	-5.4	-25.3
🟩 Gas intensity	2.2	-5.4	4.9	-4.8	-8.3	-1.2	-12.6
🟥 Electricity production	-9.6	2.9	-6.0	3.5	10.9	24.4	26.0
🟨 Change in NOx	-17.5	2.9	-23.6	3.5	5.0	17.8	-11.9

Figure 31. Decomposition of environmental impacts (NO_x emissions from gas use for electricity production), RWE 2010-2016. Variables of Equation (14b): ES=NO_x emissions from gas, PROD=electricity production from gas, and RM=gas consumption.



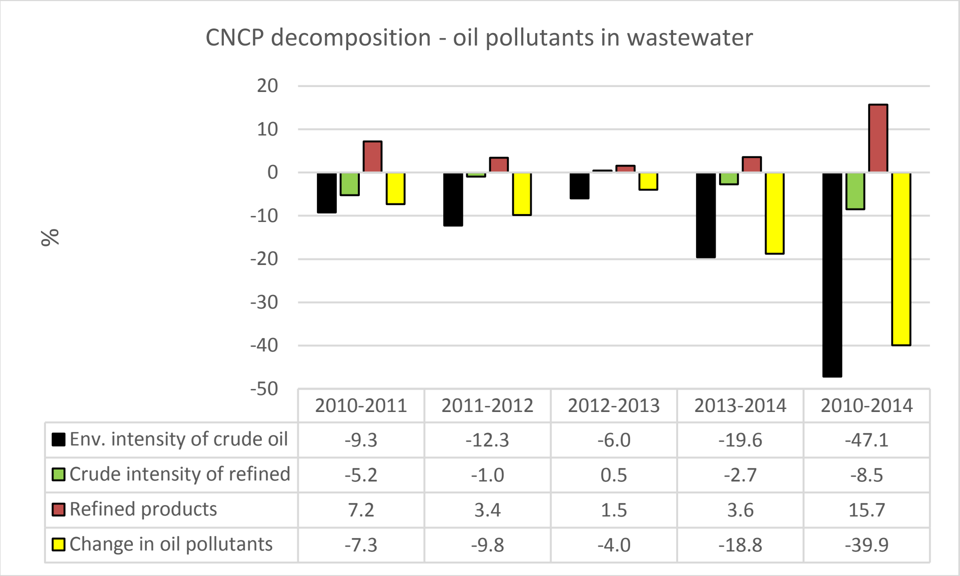
	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2010-2016
■ SO2 intensity	-2.3	5.4	-5.3	109.0	-79.3	-27.0	0.4
🟩 Gas intensity	-76.2	-76.8	-20.1	-54.0	20.9	-44.5	-250.6
🟥 Electricity production	-111.2	29.9	-65.3	51.2	67.2	234.7	206.4
🟨 Change in SO2	-189.7	-41.6	-90.8	106.2	8.8	163.2	-43.9

Figure 32. Decomposition of environmental impacts (SO_2 emissions from gas use for electricity production, RWE 2010-2016. Variables of Equation (14b): ES=SO_2 emissions from gas, PROD=electricity production from gas, and RM=gas consumption.

Change in NO_x emissions follows again the amount of NO_x intensity of the used fuel (natural gas), which has the largest decreasing effects to the change in NO_x emissions (Figure 31). Gas intensity describes the efficiency of the combustion processes, and this driver has had quite a clear decreasing effect unlike in the cases of the lignite and hard coal above.

Data on SO_2 emissions of electricity production from gas is not precise, because the emissions are so small. In the analysed data, the upper limit (below which the actual emissions are) has been used in some years, and this causes large changes at some point because the upper limit value has been used in the decomposition analysis. Thus, the decreasing and increasing effects of many drivers are extremely large (Figure 32). No strong conclusions cannot be made on the basis of this analysis and the data used.

Figure 33 shows the results from decomposition analysis of environmental impacts of CNPC. The publicly available data from this oil company includes time series data only on oil pollutants in wastewater. Data on emissions into air is available only in the most recent report. Thus, the analysis is carried out for oil pollutants in wastewater. The results show that the amount of oil pollutants has decreased annually, and the total decrease during the studied period 2010-2014 has been 40 % (Figure 33). Practically all drivers have had a decreasing effect, only the amount of production (refined oil products) has had an increasing effect to the change in the amount of pollutants in wastewater. Environmental intensity of the refining process, measured as oil pollutants in the wastewater divided by the amount of used crude oil, has had the largest decreasing effect.



	2010-2011	2011-2012	2012-2013	2013-2014	2010-2014
■ Env. intensity of crude oil	-9.3	-12.3	-6.0	-19.6	-47.1
🟩 Crude intensity of refined	-5.2	-1.0	0.5	-2.7	-8.5
🟥 Refined products	7.2	3.4	1.5	3.6	15.7
🟨 Change in oil pollutants	-7.3	-9.8	-4.0	-18.8	-39.9

Figure 33. Decomposition of environmental impacts (oil pollutants in wastewater), CNPC 2010-2014. Variables of Equation (14b): ES=oil pollutants in wastewater, PROD=total domestic refined oil products, and, RM=domestically produced crude oil.

Investments and energy efficiency in the case companies

In this chapter, the aim is to look how investments reported by the case companies affect energy efficiency and material efficiency; i.e. the drivers of energy use, production, and environmental impacts identified in Equations (11b), (12), (13c) and (14b) above.

The workshops and interviews carried out in EUFORIE WP7 revealed that companies usually do not invest in improving energy efficiency alone (Vehmas et al 2017). The major reason for an investment is elsewhere – increasing capacity, modernisation of the production process, establishing a new site of production, increasing market share, making more profit, etc. On the other hand, an investment usually introduces a new technology which is taken into use. This gives a good reason to argue that most of the investments, or even all major investments, affect also energy efficiency by improving it when compared to the situation before the investment. This makes a precise identification of an "investment in energy efficiency" a challenge, and it may also be difficult – even to representatives of the companies themselves. Here the focus is in looking for information from the publicly available company reports (annual reports, sustainability/environmental reports, corporate social responsibility reports etc.) on investments with special reference to investments explicitly called as "investments in energy efficiency".

Reported investments do not necessarily affect the values energy and material efficiency indicators (EN/PROD and PROD/RM) immediately, so that the effect could be identified during the same year. Assumption of a typical payback time (one year) for investments in energy and material efficiency gives a reason to test the following hypothesis: an investment on energy efficiency in year *t* affects the value of a chosen indicator of energy or material efficiency (or a chosen indicator of energy/material use) in the year t, t+1, or t+2. The publicly available data in the reports of the case companies from the years 2010-2015/2016 have been analysed in order to test this hypothesis.

Table 2 presents the data on investments related to energy efficiency which is available in the public reports of the five case companies. Only one of the companies, Stora Enso, connects energy efficiency explicitly to numerical data on investments, but only in the beginning of the studied period 2010-2016. Data on investments seems to be a biggest bottleneck from the point of view carrying out the analysis, where the focus is on the identification of improvements caused by the specific investments on energy efficiency. Many companies do not specify their investments, some report only environmental investments in their sustainability/environmental reports, and one of the companies gives no information of investments at all. It seems that the bigger the company, the better the investment data. However, none of the case companies gives information on investments on energy efficiency detailed enough, and only one gives the spending for investments on "energy efficiency" or "energy efficiency projects", but during a couple of years only. As a conclusion, this analysis is capable of identifying the improvements in energy efficiency, but for a proper cause-effect analysis between specific investments and the improvements, the data is insufficient. Thus, in the following only the most probable observations on a possible link between the investments and improvements in relevant drivers with a decreasing effect to the decomposed variables (energy use, primary energy use, or environmental impacts) are mentioned.

Table 2. Energy-related investment data of the four case companies.

Company	2010	2011	2012	2013	2014	2015	2016
Company 1: Stora Enso (million €)							
R&D expenditure	75	80	80	80	104	124	132
Environmental investments	37	22	23	54	32	41	41
Provisions for environmental remediation	119	126	114	106	115	100	100
Energy efficiency investment fund				***10***	***10***	***11***	***15***
Energy efficiency investments	***136***	***32***					
Energy-related projects	***142***						
Other development projects	85						
Strategic development investments			124				
Environmental costs	152	200	175	202	192	183	172
Company 2: ENEL (million €)							
Environmental investments	353	251	524	318	201	313	
• of which waste disposal, emission treatment and environmental restoration	254	142	308	226	141	196	-
• of which environmental prevention and management	99	109	216	92	60	117	-
Spending on technological innovation	87	97	127	76	74	76	-
Capital expenditure on development projects	2	4	12	8	5	8	-
Company 3: RWE Group (million €)	6379	6353	5081	4494	3245	2898	2027
Capital expenditure on property, plant and equipment							
Germany	2410	2374	1868	-	-	-	-
• Power generation	1180	1168	964	1360	1086	855	333
• Sales/distribution networks	1230	1206	904	871	900	-	-
Netherlands/Belgium	1144	971	613	28	9	-	-
United Kingdom	876	416	190	106	148	-	-
Central Eastern and South Eastern Europe	430	852	667	320	309	-	-
Renewables	614	825	999	1074	723	-	-
Upstream gas & oil	507	701	684	663	-	-	-
Trading/gas midstream	4	20	4	14	11	10	4
Other, consolidation	394	194	56	58	59	9	11
INNOGY						2024	1679
Capital expenditure of the renewables division	-	891	1093	1086	738	418	-
R&D costs	87	146	150	151	110	101	-
Company 4: Celsa							
No data on investments	-	-	-	-	-	-	-
Company 5: CNPC (millions of RBM yuan)							
Investments in public welfare	1295	1006	936	851	1008	1300	-
• of which environmental protection	316	70	165	132	109	149	-

Tables 3-7 sum up the decreasing effects of relevant drivers to the decomposed variables in the studied case companies. Investments on energy efficiency can contribute to energy intensity in industrial companies (Table 3), material intensity in industrial companies (Table 4), environmental intensity in industrial companies (Table 5), energy intensity in energy companies (Table 6), and environmental intensity in energy companies (Table 7). It is important to note that decomposition of energy use (EN), raw material (or primary energy) use (RM) and environmental impacts (ES) can include similar drivers. However, all the drivers are not necessarily included in all decompositions, due to the lack of data. The decompositions where a driver is not included, or data for a specific year/period is not available, are marked with a hyphen (-). Decompositions where a decreasing effect (either an annual, or a cumulative one for a whole period) has been identified, are marked with x. Empty cell means that the effect has been identified, but it is not a decreasing one.

Tables 3-5 show the decreasing impacts of energy intensity, material intensity and environmental intensity on the decomposed variables in the industrial companies Stora Enso and Celsa Barcelona.

Stora Enso reports about “energy efficiency investments” in the years 2010 and 2011, and decreasing effects can be observed during periods 2010-2011 and 2011-2012 (Tables 3-5). Moreover, Stora Enso reports about investments in “energy efficiency projects” in the year 2010, which seems to be the year of extremely large investments in energy efficiency. From the year 2013 onwards, smaller sums have been invested in an energy efficiency fund, but no information about the use of the fund is available. However, it seems that the quite heavy investments could explain, with a short time lag of 0-2 years, the decreasing effect of energy intensity (EN/RM; Table 3), material intensity (RM/PROD; Table 4), and environmental intensity (ES/EN; Table 5) to energy use and CO_2 emissions. During the periods 2012-2013 and 2013-2014, no decreasing effects can be identified, except the effect of material intensity in 2013-2014 to energy use and CO_2 emissions.

Celsa Barcelona does not provide any data or information about investments in energy efficiency (and investments in general). The company has had decreasing effects of the energy and environmental intensities during almost the whole studied period (Tables 3 and 5). Material intensity has not had a decreasing effect so often. A decreasing effect of environmental intensity (ES/PROD) can be identified also in the case of CO_2 emissions at the level of the four product groups (steel banks, wires and rods, structural profiles, and steel plates (Table 5).

Table 3. Energy intensity (EN/RM or EN/PROD) as a driver with decreasing effect to the decomposed variables in industrial companies. x = decreasing effect identified, - = no data available, or no such a driver in the analysis.

Company (total number of decompositions) Decomposed variable	**Decreasing effect of energy intensity** **2010-2011**	**2011-2012**	**2012-2013**	**2013-2014**	**2014-2015**	**2015-2016**	**Whole period**
Stora Enso (total 2)							
Total primary energy use (Fig. 4)	x	x			x		x
CO_2 emissions (Fig. 19)	x	x			x	x	x
Celsa Barcelona (total 5)							
Total CO_2 emissions (Fig. 20)	x	x	x	x		-	x
CO_2 emissions, steel blanks (Fig. 21)	-	-	-	-	-	-	-
CO_2 emissions, wires and rods (Fig. 22)	-	-	-	-	-	-	-
CO_2 emissions, structural profiles (Fig. 23)	-	-	-	-	-	-	-
CO_2 emissions, plates (Fig. 24)	-	-	-	-	-	-	-
Total number of decreasing effects	3	3	1	1	2	1	3

Table 4. Material intensity (RM/PROD) as a driver with decreasing effect to the decomposed variables in industrial companies. x = decreasing effect identified, - = no data available, or no such a driver in the analysis.

Company (total number of decompositions) Decomposed variable	**Decreasing effect of material intensity** **2010-2011**	**2011-2012**	**2012-2013**	**2013-2014**	**2014-2015**	**2015-2016**	**Whole period**
Stora Enso (total 2)							
Total primary energy use (Fig. 4)		x		x		x	x
CO_2 emissions (Fig. 19)		x		x		x	x
Celsa Barcelona (total 5)							
Total CO_2 emissions (Fig. 20)		x	x		x	-	
CO_2 emissions, steel blanks (Fig. 21)	-	-	-	-	-	-	-
CO_2 emissions, wires and rods (Fig. 22)	-	-	-	-	-	-	-
CO_2 emissions, structural profiles (Fig. 23)	-	-	-	-	-	-	-
CO_2 emissions, plates (Fig. 24)	-	-	-	-	-	-	-
Total number of decreasing effects	0	3	1	2	1	2	2

Table 5. Environmental intensity of energy use (ES/EN), environmental intensity of raw material use (ES/RM), or environmental intensity of production (ES/PROD) as a driver with decreasing effect to environmental impacts (ES) in industrial companies. x = decreasing effect identified, - = no data available, or no such a driver in the analysis.

Company (total number of decompositions)	**Decreasing effect of environmental intensity**						
Decomposed variable	**2010-2011**	**2011-2012**	**2012-2013**	**2013-2014**	**2014-2015**	**2015-2016**	**Whole period**
Stora Enso (total 2)							
Total primary energy use (Fig. 4)	-	-	-	-	-	-	-
CO_2 emissions (Fig. 19)	x	x			x	x	x
Celsa Barcelona (total 5)							
Total CO_2 emissions (Fig. 20)	x	x	x	x		-	x
CO_2 emissions, steel blanks (Fig. 21)	x	x	x	x		-	x
CO_2 emissions, wires and rods (Fig. 22)	x	x	x			-	x
CO_2 emissions, structural profiles (Fig. 23)		x	x		x	-	x
CO_2 emissions, plates (Fig. 24)	x		x	x		-	x
Total number of decreasing effects	5	5	5	3	2	1	6

ENEL provides data on environmental investments with two categories (waste disposal, emission treatment and environmental restoration; and environmental prevention and management), spending on technological innovation, and capital expenditure on development projects. Investments in energy efficiency are not reported, so their effect on the energy efficiency related drivers of primary energy use and environmental impacts cannot be assessed. For ENEL, decreasing effects of energy intensity can be identified in the decompositions of CO_2 emissions and decompositions of all primary energy sources (Table 6). An interesting observation is that in the incremental decomposition of the geothermal energy, energy intensity has had a decreasing effect in all periods. In periods 2012-2013 and 2013-2014, energy intensity has had a decreasing effect on the use of all primary energy sources in ENEL, except coal and biomass (Table 6). Environmental intensity of primary energy use (ES/RM) has had a decreasing effect to CO_2 emissions every second year in ENEL (Table 7). All the decreasing effects mentioned above may be related to the reported investments; especially to the highest annual sum of investments in the year 2012.

RWE is the only one of the case companies reporting data on investments in “property, plant and equipment” in their publicly available reports. For Germany, these are under two categories: “power generation” and “sales/distribution networks”. For other countries of operation, only one figure is available. Other investment categories where data is available include “renewables”, “upstream gas & oil”, “trading/gas midstream”, and “other, consolidation”. In addition to these, from the year 2015 onwards, investments are reported only in categories “power generation”, “trading/gas midstream”, and “other, consolidation”. This change is due to the establishment of INNOGY, a subsidiary of RWE dealing with businesses of renewable energy, grid and retail trade of RWE into a separate entity. The INNOGY public reports are not analysed in this deliverable. RWE, however, does not report investments in energy efficiency or environmental investments. Thus, assessing properly the relationship between RWE investments in energy efficiency and results from decomposition analysis is not possible.

Decomposition analyses for RWE show decreasing effects of energy intensity of electricity production (RM/PROD) in the case of all decomposed variables: total primary energy use and all primary energy sources, as well as environmental impacts (NO_x and SO_2 emissions of three fossil fuels, i.e. lignite, hard coal, and natural gas). A continuous trend of decreasing effects of energy intensity has been in the case of uranium during all periods 2010-2014, and in the case of natural gas during all periods 2013-2016 (Table 6). In the cases of other primary energy sources and total primary energy use, decreasing effects of energy intensity of electricity production (RM/PROD) have been occasional. In the cases of environmental impacts, energy intensity has had decreasing effects, especially on NO_x emissions of natural gas (Table 6) and occasionally on other fossil fuel specific NO_x and SO_2 emissions, too. The data on SO_2 emissions of natural gas is not exact, but still the results are included in Tables 6 and 7.

Regarding environmental impacts (total CO_2 emissions and fuel-specific NO_x and SO_2 emissions), RWE has decreasing effect of energy intensity (RM/PROD) in the case of total CO_2 emissions during all periods except the first one, 2010-2011. In the case of NO_x emissions of natural gas, the effect of energy intensity has been a decreasing one in the recent years (Table 7).

CNPC provides no data on any investments, so the relationship between investments in energy efficiency and the results from decomposition analyses cannot be done. The data provided by the Chinese CNPC is the most limited of the selected companies, and it enables two decomposition analyses of oil refining only. In the cases of primary energy (crude oil) and environmental impacts (oil pollutants in wastewater, the only one indicator with time series data available in the reports), a decreasing effect of energy intensity (RM/PROD) can be identified during all periods where data is available except 2012-2013. Environmental intensity (ES/RM) has a decreasing effect in all the studied periods.

Table 6. Energy intensity of electricity production (RM/PROD) as a driver with decreasing effect to the decomposed variables in energy companies. x = decreasing effect identified, - = no data available, or no such a driver in the analysis.

Company (total number of decompositions)	**Decreasing effect of material (primary energy) intensity (RM/PROD)**						
Decomposed variable	**2010-2011**	**2011-2012**	**2012-2013**	**2013-2014**	**2014-2015**	**2015-2016**	**Whole period**
ENEL (total 8)							
Total primary energy use (Fig. 5)			x	x		-	
Decomposition of coal use (Fig. 6)	x					-	x
Gas and oil use (Fig. 7)	x		x	x		-	
Uranium use (Fig. 8)			x	x		-	x
Renewables use (Fig. 9)		x	x	x		-	x
Geothermal use (Fig. 10)	x	x	x	x	x	-	x
Biomass use (Fig. 11)		x			x	-	
CO_2 emissions (Fig. 25)		x	x	x		-	
RWE Group (total 13)							
Total primary energy use (Fig. 12)			x			x	
Lignite use (Fig. 13)		x	x				x
Hard coal use (Fig. 14)	x					x	
Natural gas use (Fig. 15)		x		x	x	x	x
Uranium use (Fig. 16)	x	x	x	x		x	x
Biomass use (Fig. 17)	x					x	
CO_2 emissions (Fig. 26)			x			x	
NO_x emissions, lignite (Fig. 27)		x	x				x
SO_2 emissions, lignite (Fig. 28)		x	x				x
NO_x emissions, hard coal (Fig. 29)	x					x	
SO_2 emissions, hard coal (Fig. 30)	x					x	
NO_x emissions, gas (Fig. 31)		x		x	x	x	x
SO_2 emissions, gas (Fig. 32)	x	x	x	x		x	x
CNCP (total 2)							
Crude oil use (Fig. 18)	x	x		x	x	-	x
Oil pollutants in wastewater (Fig. 3)	x	x		x	-	-	x
Total number of decreasing effects	11	13	13	12	5	10	13

Table 7. Environmental intensity of primary energy (ES/RM) as a driver with decreasing effect to the decomposed variables in energy companies. x = decreasing effect identified, - = no data available, or no such a driver in the analysis.

Company (total number of decompositions)	**Decreasing effect of environmental intensity (ES/RM)**						
Decomposed variable	**2010-2011**	**2011-2012**	**2012-2013**	**2013-2014**	**2014-2015**	**2015-2016**	**Whole period**
ENEL (total 8)							
Total primary energy use (Fig. 5)	-	-	-	-	-	-	-
Coal use (Fig. 6)	-	-	-	-	-	-	-
Gas and oil use (Fig. 7)	-	-	-	-	-	-	-
Uranium use (Fig. 8)	-	-	-	-	-	-	-
Renewables use (Fig. 9)	-	-	-	-	-	-	-
Geothermal use (Fig. 10)	-	-	-	-	-	-	-
Biomass use (Fig. 11)	-	-	-	-	-	-	-
CO$_2$ emissions (Fig. 25)	x		x		x	-	x
RWE Group (total 13)							
Total primary energy use (Fig. 12)	-	-	-	-	-	-	-
Lignite use (Fig. 13)	-	-	-	-	-	-	-
Hard coal use (Fig. 14)	-	-	-	-	-	-	-
Natural gas use (Fig. 15)	-	-	-	-	-	-	-
Uranium use (Fig. 16)	-	-	-	-	-	-	-
Biomass use (Fig. 17)	-	-	-	-	-	-	-
CO$_2$ emissions (Fig. 26)		x	x	x	x	x	x
NO$_x$ emissions, lignite (Fig. 27)				x		x	x
SO$_2$ emissions, lignite (Fig. 28)		x		x	x	x	
NO$_x$ emissions, hard coal (Fig. 29)		x		x	x	x	x
SO$_2$ emissions, hard coal (Fig. 30)				x	x	x	x
NO$_x$ emissions, gas (Fig. 31)	x		x			x	x
SO$_2$ emissions, gas (Fig. 32)	x	x	x				x
CNCP (total 2)							
Crude oil use (Fig. 18)	-	-	-	-	-	-	-
Oil pollutants in wastewater (Fig. 3)	x	x	x	x	-	-	x
Total number of decreasing effects	4	5	5	6	5	6	8

Conclusions

In this deliverable, the decomposition of energy use, raw material use, and environmental impacts in the selected case companies was carried out by using the publicly available data from the company reports from a time period 2010-2016 (in some of the companies 2015). The incremental chained two-factor decomposition developed in EUFORIE deliverable D2.1 was used also in this deliverable; annual changes are the most interesting in the case of company-level analysis, The relationship between investments in energy efficiency and the (decreasing) effects of energy efficiency related drivers (energy intensity, material intensity, and environmental intensity) of all decomposition analyses was looked as well. As a driver of energy consumption, use of raw materials, and environmental impacts, these intensities have had annual decreasing effects in almost all of the 29 cases of decomposition analysis (of energy use, raw material use, and environmental impacts) of the studied five companies. However, the “rebound effect” is significant; in some of the cases, the decreasing effect of decreased energy intensity has been overdriven by the increased amount of production. As a result energy consumption, raw material consumption, and environmental impacts such as CO_2 emissions and others, have increased.

The studied period 2010-2016 (in some cases 2010-2015 and in one case 2010-2014) is quite short, so no strong conclusions cannot be drawn on the basis on the incremental analyses or their sums describing the whole period. However, the amount of production is the most important driver of energy and raw material consumption as expected; energy intensity, material intensity and environmental intensity usually slows down the increase of energy and raw material consumption and environmental impacts.

Expectations of the possibility to see the effect of investments in energy efficiency to energy consumption and environmental impacts of the companies was quite high before the analysis, but the data on investments very rarely included precise information whether the investment has been on energy efficiency or not. On the other hand, participatory workshops and interviews carried out in EUFORIE WP7 gave reason to assume that many investments affect energy efficiency, although they are not directly related to it (see EUFORIE deliverable D7.1). With keeping this in mind, some interesting correlations between investments during specific years and decreasing effects of energy intensity during the same year or one year later can be found. This is in line with the fact that the payback time of investments in energy efficiency, expected by the companies, is typically short, perhaps around one year.

All the case companies are big companies, most of them have a long history in environmental and corporate social responsibility reporting. SMEs do not usually provide this kind of reports available for the public audience. One of the objectives of this deliverable was to identify improvement needs for company reporting, especially the amount, type and quality of reported data. This objective was approached from the point of view of the data requirements of decomposition analysis. The identified improvement possibilities offer the companies in general an opportunity to inform different stakeholders about the performance of the company in a more detailed way.

The results show that the availability of data between the selected case companies varies quite a lot. Tables 3-7 presented above show that mainly due to the availability of data, the number of decomposition analyses carried out for the case companies varies between companies, i.e. between industrial companies and between energy companies. The companies with a large number of analyses offer also other than company level data; data is available on product or fuel level as well, like in ENEL, RWE, and Celsa Barcelona. The aim of this deliverable is to provide general recommendations for all industrial and energy companies regarding the data needs of a performance analysis using the ASA decomposition methodology.

The data needs of the ASA decomposition approach are similar at all levels, from the aggregated company/corporation level to a detailed product level, and all levels in between. At least the following levels, all relevant for a company's performance, can be identified for a decomposition analysis:

1. whole company/corporation
2. all production sites inside a country (or another geographical area)
3. a production site
4. a production process (in a production site)
5. an individual product (or a product group).

The analyses done in this deliverable represent levels 1, 5 and 6 of the whole company. The data challenge comes from the fact, that the ASA decomposition requires all data from the same level in a single unit of measure. This may be in practice difficult, especially when a company has several production sites in many different countries all over the World, uses many different energy sources, many different raw materials, has many different subcontractors, and produces a large variety of different products. In addition to the availability of data at the same level, the ASA decomposition is always based on a choice of variables – for a single analysis, choice needs to be made for all variables used in the analyses. The publicly available data in the selected case companies' annual, environmental, and corporate social responsibility reports, clearly shows the challenge. The following general improvement needs can be identified on the basis of this study:

- **Time series data**. An important perspective to a company's performance is change over time. Thus, time series data is needed, and the suggestion for company reporting is to provide data not only in comparison to the previous year, but also in comparison to the development during 5-10 years.
- **Data on investments**. Companies very rarely provide specific data on investments. Investments in production processes are of importance here. Renovation of a production process is an investment also in energy efficiency, in addition to investments where the only purpose is to reduce energy consumption.
- **Monetary data in real prices**. Companies provide usually a lot of monetary information because the shareholders are interested in it. Combined to time series data, the use of real price is expected. This is important if development for a longer period in turnover, sales, value added, or investments etc. is considered.
- **Disaggregated data**. In big companies with several sites of production, data describing the whole company is heavily aggregated. Less aggregated data would enable a more detailed analysis. Data per production site and per production process would give an opportunity to see the real reasons for changes in company performance. Disaggregated data is a challenge, if many different raw materials and energy sources/carriers are used to produce many different products in several sites of production. The data on the use of each raw material and each energy carrier in each production site and production process usually exists – it only needs to be reported.

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