EUFORIE
European Futures for Energy Efficiency

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European Futures for Energy Efficiency

Report of energy efficiency at company level

WP6 Deliverable D6.2

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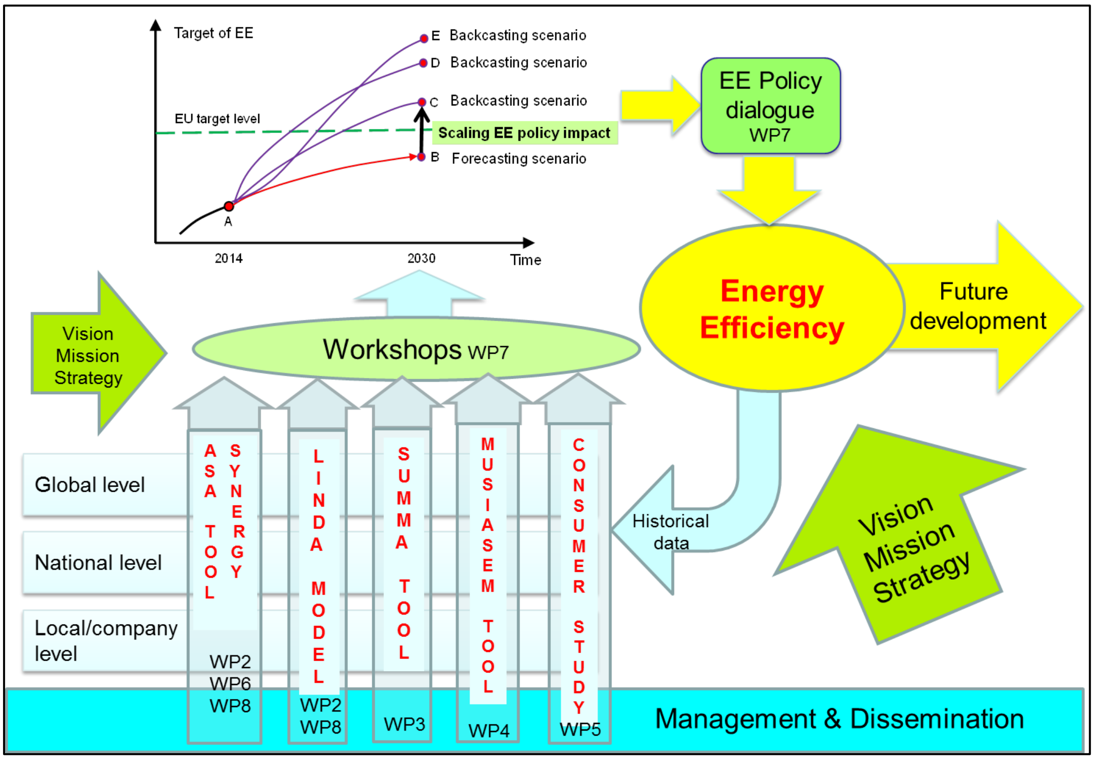
The EUFORIE project

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 develop and test new efficiency indicators for companies. The indicators should describe change in energy, material and environmental efficiency better than the commonly used specific consumptions and specific emissions (calculated per unit of production) do from the sustainability point of view. The indicators should give more information about the company's energy, material and environmental performance than the existing indicators.

The task of indicator developing is done by refining results from a two-factor decomposition of energy use, material use, and environmental output. The results, activity and intensity effects, can be calculated by a preferred decomposition technique. From the activity and intensity effects, it is possible to calculate

1. how much the activity effect can change without an increase in energy use, material use, or harmful environmental outputs, and
2. how much the intensity effect needs to change from the original value, that energy use, material use, or harmful output to the environment will not increase.

By doing this the possible rebound effect will be taken into consideration, which is important from the sustainability point of view. As a result, two new indicators will be introduced: sustainable growth (SG) and sustainable intensity (SI). They can be calculated as follows:

$$SG = -\frac{Intensity\ effect}{Activity\ effect} \times 100\ \%$$

$$SI = -\frac{Activity\ effect}{Intensity\ effect} \times \frac{V_0}{V_t}$$

where V_0 is the original value and V_t the changed value of the selected indicator describing energy use, material use, or environmental output during the studied time period. SG shows the "sustainable" part as percentage from the observed activity change. SI is a coefficient: multiplying the observed intensity effect with the SI coefficient tells the "sustainable" intensity effect. A good thing in these new indicators is that they are applicable at any level of economic activity, and the variables to be included in the analysis can be chosen by the user. A causal relationship between the chosen variables is expected and assumed. Typical examples of an assumed causal relationship include:

- production explains energy use
- production explains material use
- production explains environmental output
- energy use explains environmental output
- material use explains environmental output.

The indicators SG and SI have also their weaknesses and challenges of interpretation. They are not stand-alone indicators, because similar values may be a result from different situations. Details for this can be found in this deliverable.

The task of testing the new indicators is done by calculating the SG and SI indicator values for selected case companies by using different combinations of publicly available data from the company websites, open databases, and environmental and other company reports. The case companies include three energy companies: ENEL (Italy), RWE (Germany) and CNPC (China), and two industrial companies: Stora Enso (pulp and paper, Finland/Sweden) and Celsa Barcelona (metal products, Catalonia/Spain). Several tests for each company have been done. In the tests, activity is measured by the amount of production, but in some tests also by energy or raw material use. Intensity is measured by dividing energy or material use, or environmental output by the activity variables. The tests are done by using the various possibilities offered by the selected data. The analysis covers the years from 2010 to the most recent year with the publicly available data.

Based on the tests, the production/economic activity of the European companies has not always increased. Often it has decreased, especially in terms of annual changes. Decreasing production (activity effect) has usually decreased also energy use, material use and environmental output more than the intensity effect has changed them. In the light of the SG and SI indicators, performance of the companies, especially the industrial companies Stora Enso and Celsa Barcelona, is determined by the changing activity. Another observation is that during the relatively short period analysed (2010-2016), the intensity effect does not usually play a major role in decreasing energy use, material use, or environmental impact.

This study brought out additional improvement possibilities to company reporting. Regarding the operational performance from the sustainability point of view, the indicators SG and SI could provide additional information. The results are useful for companies, especially to those willing to improve environmental and sustainability reporting. The developed indicators SG and SI are applicable to any system, so there are options available to apply them also elsewhere than in companies. The results may be of interest also to policy makers in the EU and individual Member States, for NGOs and all stakeholders interested in energy, material and environmental performance of economic systems and organisations. The developed indicators are first versions and have their weaknesses, but they offer also a starting point for further improvements done by sustainability-oriented researchers.

Tasks of this deliverable related to WP6, WP7, WP8 and WP9

This deliverable D6.2 covers the following tasks in EUFORIE WP6 (Microeconomic efficiency analysis of selected case companies):

- Task 6.2 “Developing new indicators of changing energy efficiency at company level in collaboration with the selected case companies. Using the results as input for WP7 and WP8.

The results have been used as input in WP7 Task 7.5 “The roundtable of European energy efficiency and strategy”, arranged in Brussels on 27th September 2018 under the title “From physics to policy: Overcoming misperceptions in energy policy”.

The developed indicators are calculated for all European case companies selected in WP6, and for the Chinese case company selected in WP8 Task 8.5 “Company level analysis”.

The developed indicators were chosen as a topic of Policy Brief 3 (D9.8), which was produced in WP9.

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Abbreviations

Abbreviation	Explanation
A_{eff}	Activity effect
ASA	Advanced Sustainability Analysis
CASS	Chinese Academy of Social Sciences
CNPC	Chinese National Petroleum Company
CO_2	Carbon dioxide (emissions)
EN	Energy use, consumption
ENEL	Italian energy company
ES	Environmental impact (environmental stress)
EU	European Union
EUFORIE	European Futures for Energy Efficiency
GDP	Gross Domestic Product
I_{eff}	Intensity effect
NO_x	Nitrous oxide(s) (emissions)
PROD	Production (physical amount of)
RM	Raw Material (use, consumption)
RWE	German energy company
SG	Sustainable Growth
SI	Sustainable Intensity
SO_2	Sulphur dioxide (emissions)
WP	Work Package

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Goals of this deliverable

In this EUFORIE deliverable D6.2, the focus is on energy efficiency, material efficiency, and environmental 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. The same deals with material and environmental efficiencies, which are important things to take into consideration in addition to energy efficiency, as pointed out in the EUFORIE work packages WP3 (Ulgiati et al 2017) and WP7 (Vehmas et al 2017). A detailed technology-specific analysis, however, is not the purpose of EUFORIE WP6 and its deliverables. Instead, the purpose is to develop indicators describing changing energy, material and environmental efficiency at the company level. The indicators describe the performance and they can be applied to industrial and economic systems at different levels from individual products via specific production processes to a production site, company, and a corporation as a whole.

To reach these goals, the Advanced Sustainability Analysis (ASA) framework applied in the EUFORIE deliverable D6.1 (Vehmas & Ameziane 2017) is taken as the starting point. The two-factor decomposition analysis shows the effects of changing activity and intensity either to energy consumption, raw material consumption, or environmental outputs. The new performance indicators can be calculated from these effects. The indicators will be tested by using publicly available data collected in the EUFORIE deliverable D6.1 for selected case companies.

Introduction: 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 efficiency has been a common policy goal all over the World. Using less raw materials and less energy for a certain task with less environmental impacts decreases material and energy consumption, total environmental impacts and related costs.

In companies, energy and raw materials are inputs of the production system. Efficiency refers to a relationship between the input to the system and the output from the system. The more output the system produces by using one unit of input, the more efficient the system is (Equation 1):

$$Efficiency = \frac{Output}{Input} \quad (1)$$

When input decreases and the output remains the same, efficiency increases. This kind of definition is valid in all systems, and it does not depend on the scale or type of the investigated system *per se*. However, in practice, the system boundary must be clearly defined. In large systems, the energy and material input usually consists of many different types of energy and materials. Calculating total efficiency of a large system requires first consideration of total input to the system. Thus, aggregation may be needed. On the other hand, also the output should be considered in total terms, if the goal is to squeeze efficiency into one figure. This makes the use of monetary units attractive if the physical units cannot be easily aggregated. It is also possible to calculate "partial" efficiencies by selecting specific inputs and outputs. In EUFORIE WP4, a different approach, end-use matrix, to evaluating efficiency of large systems is proposed (Giampietro et al 2017).

In this deliverable, three types of efficiency are in focus: energy efficiency, material efficiency, and environmental efficiency. Energy and materials are typically inputs of a productive system, but in some processes, outputs include energy and materials as by-products. Environmental impacts are typically caused by unwanted environmental outputs such as waste and emissions into air, water and soil.

Intensities can be defined as relationships between (1) inputs and outputs, (2) different inputs, (3) different outputs, as well as (4) outputs and inputs. The following types of intensities are taken into account:

- Energy intensity of material use: energy use/material use (input/input)
- Energy intensity of production: energy use/production (input/output)
- Material intensity of production: material use/production (input/output)
- Environmental intensity of energy use: environmental output/energy use (output/input)
- Environmental intensity of material use: environmental output/material use (output/input)
- Environmental intensity of production: environmental output/production (output/output).

Case companies

In this deliverable, energy, material and environmental performance of selected case companies will be analysed. The suggested new indicators (presented in the next chapter) will be calculated by using the publicly available data provided by these companies.

The selection of case companies was based on two criteria: (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. The case companies selected analyses include (Vehmas & Ameziane 2017) the following:

1. Stora Enso, Finland, a large international producer of paper and board, biomaterials, and wood products
2. ENEL, Italy, one of the largest multinational producers and distributors of electricity and gas internationally
3. RWE, Germany, one of the key electricity and gas utilities in Europe
4. Celsa Barcelona, Spain, a metallurgical company part of the Celsa Group, that specializes in the production of steel plates, wire rods, channels and electro-welded mesh products
5. CNPC (China National Petroleum Corporation), a large, Chinese state-owned integrated oil corporation, which produces crude oil and refines it into petroleum products.

The companies were suggested by the EUFORIE partners and Chinese Academy of Social Sciences (CASS). Detailed company descriptions are available in the EUFORIE deliverable D6.1 (Vehmas & Ameziane 2017), so they are not repeated here.

Methodology

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 change over time in environmental, social, and economic performance, measured by selected variables describing these dimensions. In this deliverable, the focus is on environmental performance and environmental sustainability. The choice of variables enables using the ASA approach for specific topics such as material, energy, and environmental performance.

The basic ASA approach applies a two-factor decomposition analysis (Figure 1) to divide an observed change in the environmental variable (V) into two effects: activity effect (effect of variable X describing the activity) and intensity effect (effect of variable Y=V/X describing the intensity). At all time moments, V = XY.

V_{t-1} and V_t are the rectangle areas which describe the environmental output (V) at time moments *t-1* and *t* in Figure 1. The change in variable V (ΔV_{tt-1}) consists of the own effect of variable X (activity), the own effect of variable Y =V/X (intensity) and the joint effect of both variables X and Y (Figure 1). The problem now is the joint effect of variables X and Y=V/X (dotted area in Figure 1). How should it be dealt with in order to make a perfect decomposition?

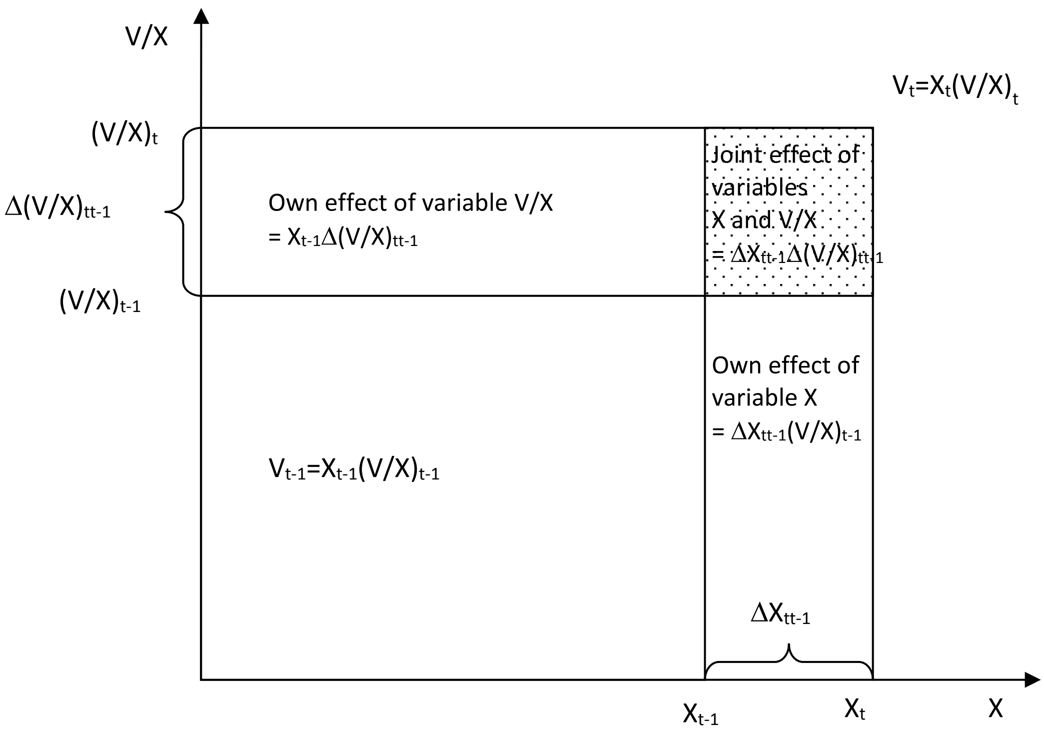

Figure 1. The separate effects and joint effect of activity X and intensity V/X to the change in variable V from time slot *t-1* to *t* (modified from Sun 1996, 48).

In general terms, the contributions of variables V/X and can be calculated by using the following Equations (Equations 2-4b). At all time moments,

$$V = X \times \frac{V}{X} \tag{2}$$

The difference in intensity (Y/X) between time moments *t-1* and *t* is

$$\Delta\left(\frac{V}{X}\right)_{tt-1} = \left(\frac{V}{X}\right)_{t} - \left(\frac{V}{X}\right)_{t-1} \tag{3a}$$

and difference in activity (X) between time moments *t-1* and *t* is

$$\Delta X_{tt-1} = X_t - X_{t-1} \tag{3b}$$

Based on Figure 1, the effect of changing intensity to variable V between time moments *t-1* and *t* is now the intensity effect $(V/X)_{eff}$:

$$\left(\frac{V}{X}\right)_{eff} = \left(X_{t-1} + \lambda \Delta X_{tt-1}\right) \times \Delta\left(\frac{V}{X}\right)_{tt-1} \tag{4a}$$

Based on Figure 1, the effect of changing activity X to variable V between time moments *t-1* and *t* is the activity effect X_{eff}:

$$X_{eff} = \left[\left(\frac{V}{X}\right)_{t-1} + (1-\lambda)\Delta\left(\frac{V}{X}\right)_{tt-1}\right] \times \Delta X_{tt-1} \tag{4b}$$

In Equations (4a) and (4b), parameter λ (0 ≤ λ ≤ 1) determines how the joint effect will be allocated to the intensity and activity effects. Figure 2 below describes theoretical alternatives in graphical format. Choosing λ=0, the whole joint effect will be allocated to activity effect (X). Choosing λ=1 allocates the whole joint effect to the intensity effect (V/X).

In theory, any value between 0 and 1 (0 ≤ λ ≤ 1) can be given to parameter λ. 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 this deliverable. This method, called first as "refined Laspeyres method" and later as "Sun/Shapley method" has been included in the recommended decomposition methods by Ang (2004)[1], because it provides a perfect decomposition by allocating the residual term with a principle "jointly created, equally distributed" to the identified drivers.

[1] Later, decomposition methods based on the Divisia index have gained more popularity and the Sun/Shapley method has been less used (Ang 2015).

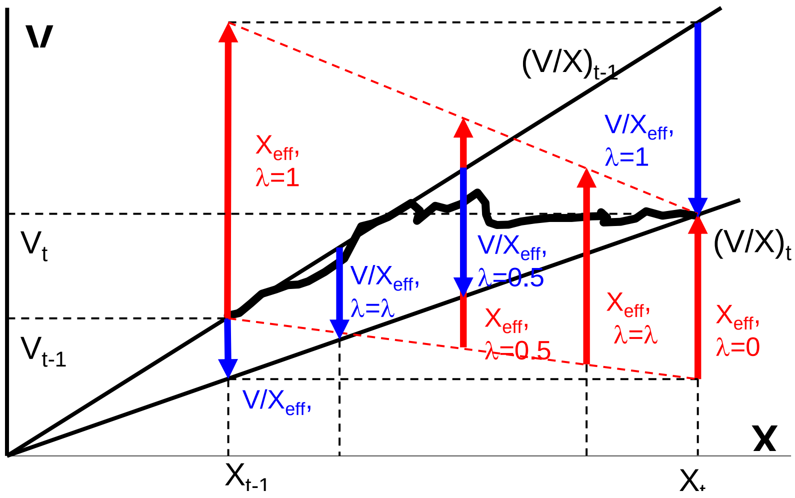

Figure 2. Decomposition of change in variable V into the contributions of variables X and V/X by using different values for parameter λ.

Sustainability performance indicators based on the ASA approach

The criterion for sustainability in the ASA approach is simply that the value of variable V (e.g. energy consumption, material consumption, or any environmental impact) does not increase over time, i.e. $\Delta V \leq 0$ ($V_t - V_0 \leq 0$). Because in a two-factor decomposition ΔV is a sum of the activity effect (X_{eff}) and the intensity effect (Y_{eff}), the performance indicators will be defined on the basis of these two effects. The effects can be calculated by any available decomposition technique, so using the two-factor Sun-Shapley decomposition presented above is not necessary.

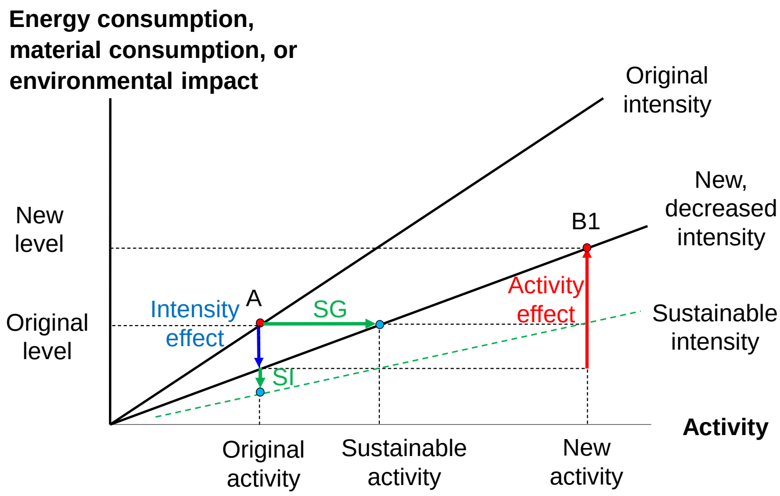

Figure 3. Graphical definition of the performance indicators sustainable growth (SG) and sustainable intensity (SI). Sustainability criterion is that energy consumption, material consumption, or environmental output/impact does not increase during the studied change (from point A to point B1).

Figure 3 above gives graphical definitions for the new performance indicators. Sustainable growth (SG) describes how much the activity X can change from the original value with the new, changed intensity until the limit set by the sustainability criterion will be met (Figure 3). This amount can be calculated from the activity effect and intensity effect in the following way (Vehmas 2004, see also Ilvonen 2004):

$$SG = -\frac{Intensity\ effect}{Activity\ effect} \times 100\ \% \qquad (5)$$

In practice, the SG can be smaller or larger than the observed change. It can be even negative, because either activity or intensity can also decrease over time. The SG is calculated as percentage (%) from the observed activity change. Interpretation of the result depends on the direction of change in all variables V, X, and Y (V/X), see Figures 5-10 and the related texts below.

Sustainable intensity (SI) describes what the intensity effect should be that the observed change in activity would not increase the value of variable V (Figure 3). This intensity is calculated in the following way (Vehmas 2004; see also Ilvonen 2004):

$$SI = -\frac{Activity\ effect}{Intensity\ effect} \times \frac{V_0}{V_t} \qquad (6)$$

The SI can be smaller or larger than the observed intensity effect, and it can also be negative because change in either activity or intensity can also be negative. The SI is defined here as a coefficient. The intensity effect fulfilling the ASA sustainability criterion is calculated by multiplying the observed intensity with the SI coefficient. Ina similar way than in the case of SG, interpretation of the result depends on the direction of change in all variables V, X and Y (V/X), see Figure 4.

The ASA sustainability criterion ($\Delta V \leq 0$) can be fulfilled in several ways depending on change in the drivers, i.e. values of the variables X and V/X in the ASA framework. In theory, six different cases are possible (B1-B6; Figure 4). Intensity decreases in cases B1-B3 (Figure 4, left side), and increases in cases B4-B6 (Figure 4, right side). In three cases (B2, B3 and B6), $\Delta V \leq 0$, so these cases fulfil the ASA sustainability criterion, and the other three (B1, B4 and B5) do not. Keeping this in mind, in cases B2, B3 and B6 the performance indicators SG and SI may “allow” an increase in activity X and intensity V/X, because the performance shows a decrease in variable V, and the system can increase the value of V until it reaches the original level (point A; see also Figure 3). In cases B1, B4 and B5 there is an increase in variable V, so decreasing effects are needed to fulfil the ASA sustainability criterion.

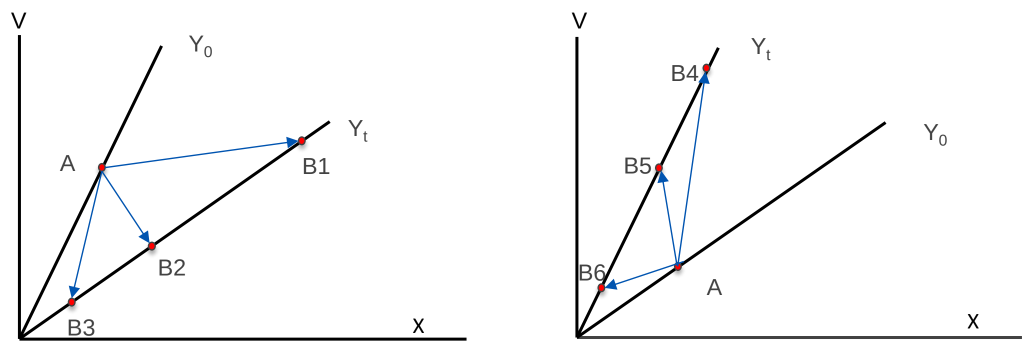

Figure 4. Six cases (B1-B6) of change in the two-factor ASA sustainability framework. In the left figure, intensity decreases ($Y_0 > Y_t$) and in the right figure, intensity increases ($Y_0 < Y_t$).

Figures 5-10 show the graphical definition of the sustainability performance indicators SG and SI in the six cases B1-B6 shown in Figure 4. In all Figures 5-10, the vertical blue arrow is the intensity effect, and the vertical red arrow is the activity effect. The vertical green arrow describes the “additional” intensity effect needed to reach the SI with the observed change in activity X, and the horizontal green arrow describes the SG.

Figure 4 shows the first case B1, which is used here now to introduce the concepts based on the ASA approach, including the sustainability performance indicators SG and SI. This case is the easiest one for explaining the concepts, but not necessarily the most common one in practice. In this case, activity X increases ($X_t > X_0$) and intensity V/X decreases but not enough, so the decomposed variable V (energy consumption, material consumption of environmental impact) increases ($V_t > V_0$), so the performance is not sustainable. In the case B1, however, part SG of the observed activity increase ΔX, defines and empirically estimates the part of the increased activity, which can be considered as sustainable. This is the core idea of SG in the ASA approach. If SG is presented as percentage of the observed activity change (Equation 5), the value is 0 < SG < 100 %.

To reach sustainability with the observed activity change in the case B1 (Figure 5), the intensity effect should be larger than the observed one (blue vertical arrow). In other words, the intensity should be $(V/X)'_t$ (green dashed line) instead of $(V/X)_t$. The vertical green arrow shows how much larger the intensity change should be, and the concept of SI defines and empirically estimates how much larger the intensity should be, i.e. how much more efficient the performance should be that the same activity could be performed without an increase in the variable V. The coefficient SI, which defines the required intensity effect in Equation (6), gets in this case B1 a value SI > 1.

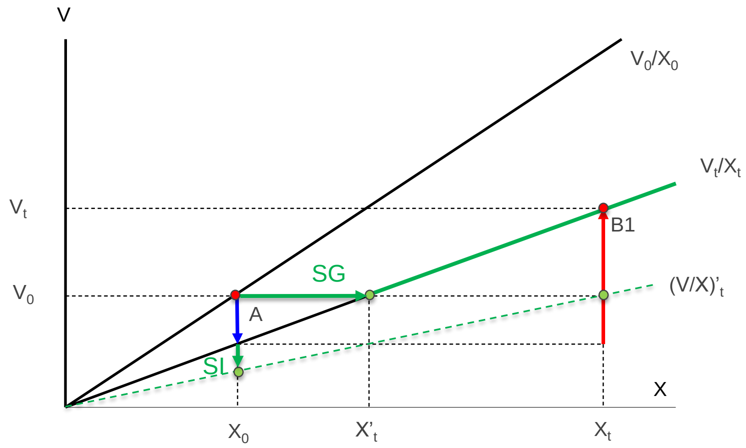

Figure 5. Graphical definition of suggested sustainability performance indicators in the case B1 where ΔV > 0, ΔX > 0, and ΔY < 0.

Figure 6 introduces the case B2, where activity X increases and intensity V/X decreases and the decomposed variable V (energy consumption, material consumption of environmental impact) decreases ($V_t < V_0$). Performance in this case is sustainable. Now SG is larger than the observed activity increase ΔX, and if SG is presented as percentage of the observed activity change (Equation 5), the value is SG > 100 %. In this case B2, with the observed activity change ΔX, the intensity effect could be smaller than the observed intensity effect Δ(V/X). The vertical green arrow shows how much smaller the intensity change should be. The coefficient SI, which defines the required intensity effect in Equation (6) above, gets a value SI < 1 in this case B2.

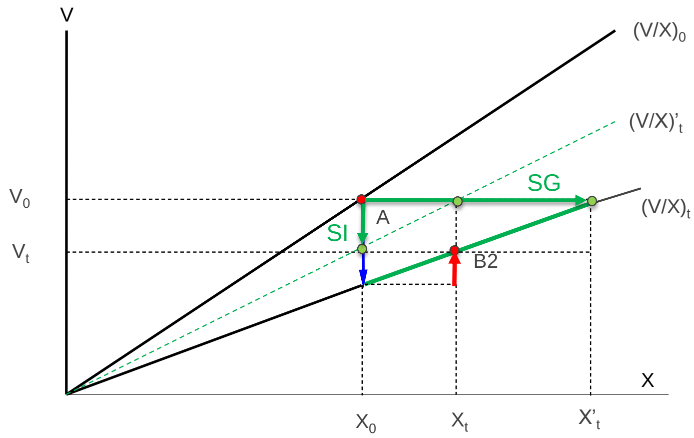

Figure 6. Graphical definition of suggested sustainability performance indicators in the case B2 where ΔV < 0, ΔX > 0, and ΔY < 0.

Figure 7 illustrates the case B3. In this case, activity X decreases and intensity V/X decreases. Both intensity and activity effects decrease the value of the decomposed variable V (energy consumption, material consumption of environmental impact), so performance in this case is also sustainable. Now SG is negative, so the activity X could even increase without threatening sustainability. The SG value, presented as percentage of the observed activity change (Equation 5), is now SG < 0 %. In this case, with the observed activity change, the intensity could even increase. The vertical green arrow shows how much the intensity could increase. The coefficient SI, which defines the possible increase in the intensity effect in Equation (6) above, gets in this case B3 a negative value (SI < 0).

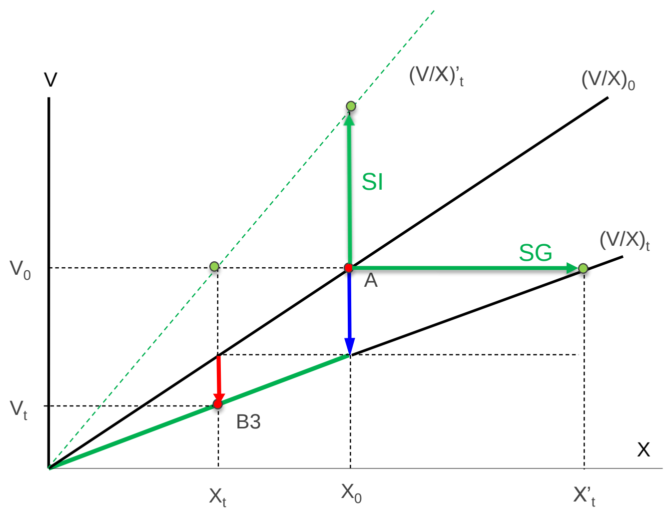

Figure 7. Graphical definition of suggested sustainability performance indicators in the case B3 where ΔV < 0, ΔX < 0, and ΔY < 0.

Figure 8 shows the case B4. In this case, both activity X and intensity V/X increase. Thus, both intensity and activity effects increase the value of the decomposed variable V (energy consumption, material consumption of environmental impact), so performance in this case is not sustainable. SG is negative, so the activity X should decrease instead of the observed increase to reach sustainability with the new performance, increased intensity. The SG value, presented as percentage of the observed activity change (Equation 5), is SG < 0 %. In this case, with the observed activity change, the intensity should decrease that the variable V could keep its original value. The vertical green arrow shows how much the intensity should decrease. The coefficient SI, which defines the required decrease in the intensity effect in Equation (6), gets in this case B4 a negative value (SI < 0).

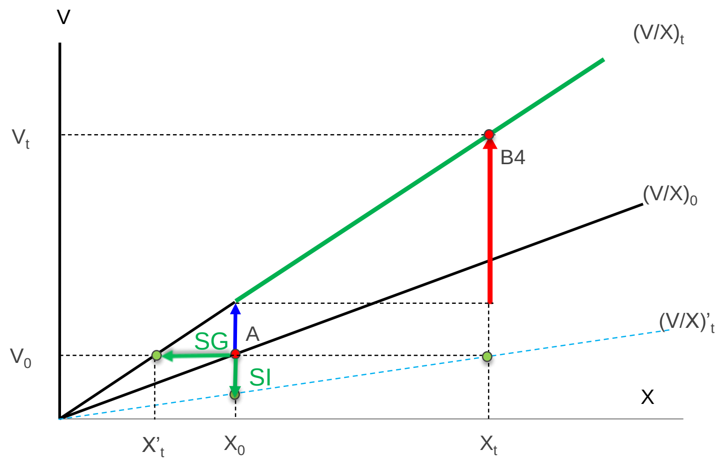

Figure 8. Graphical definition of suggested sustainability performance indicators in the case B4 where $\Delta V > 0$, $\Delta X > 0$, and $\Delta Y > 0$.

Figure 9 illustrates the case B5. In this case, intensity V/X increases and activity X decreases, but the variable V (energy consumption, material consumption of environmental impact) increases so that the performance is unsustainable. Now SG gets a positive value SG > 100 % from the observed activity change (Equation 5). In other words, the observed decrease in activity X is not enough to meet the sustainability criterion ($\Delta V \leq 0$), so the decrease in X should be larger. In this case, with the observed activity change, the increase in intensity V/X should be smaller in order to have a sustainable performance. The vertical green arrow shows how much smaller the intensity should be. The coefficient SI defined in Equation (6), gets in the case B5 a value 0 < SI < 1.

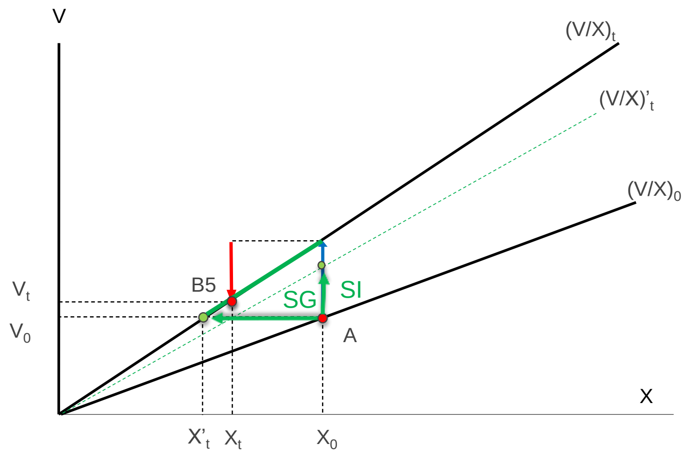

Figure 9. Graphical definition of suggested sustainability performance indicators in the case B5 where $\Delta V > 0$, $\Delta X < 0$, and $\Delta Y > 0$.

Figure 10 illustrates the last one of the six cases, case B6. Also in this case, activity X decreases and intensity V/X increases, but now the decomposed variable V (energy consumption, material consumption of environmental impact) decreases. Performance in this case is sustainable by definition, but because intensity increases it can be considered as quasi-sustainable performance. SG gets a value 0 < SG < 100 % from the observed activity change (Equation 5). This means that the activity effect decreases the variable V value more than the intensity effect increases it. In this case, with the observed activity change, the increase in intensity could be even larger than the observed one without threatening sustainability. The vertical green arrow shows how much larger the intensity could be. The coefficient SI defined in Equation (6) gets in the case B6 a value SI > 1.

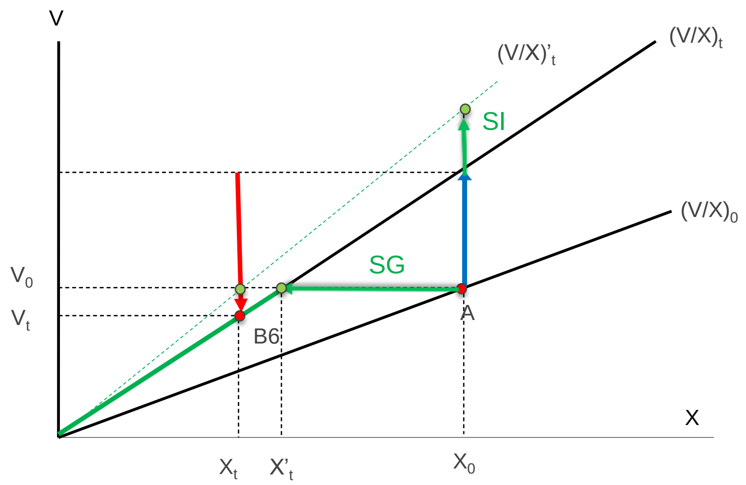

Figure 10. Graphical definition of suggested sustainability performance indicators in the case B6 where $\Delta V < 0$, $\Delta X < 0$, and $\Delta Y > 0$.

Table 1 below summarizes the information of the six different cases B1-B6 of change in the ASA framework presented above in the context of Figures 5-10. When interpreting the results regarding the SG and SI, it is important to recognize the case. This, in addition to the SG and SI values, information about the change in the variable V (ΔV) is important, because the possible SG and SI values have a same range in the cases B1 (unsustainable) and B6 (sustainable), B2 (sustainable) and B5 (unsustainable), and B3 (sustainable) and B4 (unsustainable). The sustainability performance indicators are thus not "stand-alone" indicators, but their interpretation is clear in each of the cases B1-B6. Table 1 also lists corrective actions, which are needed to change the performance towards the sustainability criterion. In the sustainable cases, the actions are in parenthesis, because they are not necessary but are possible without violating the sustainability criterion.

Table 1. Summary of the six cases of change in the ASA sustainability performance framework.

	A-B1	**A-B2**	**A-B3**	**A-B4**	**A-B5**	**A-B6**
X	$X_0 < X_t$	$X_0 < X_t$	$X_0 > X_t$	$X_0 < X_t$	$X_0 > X_t$	$X_0 > X_t$
V	$V_0 < V_t$	$V_0 > V_t$	$V_0 > V_t$	$V_0 < V_t$	$V_0 < V_t$	$V_0 > V_t$
Y=V/X	$Y_0 > Y_t$	$Y_0 > Y_t$	$Y_0 > Y_t$	$Y_0 < Y_t$	$Y_0 < Y_t$	$Y_0 < Y_t$
Y_{eff}	< 0	< 0	< 0	> 0	> 0	> 0
X_{eff}	> 0	> 0	< 0	> 0	< 0	< 0
Size of effects	$\lvert X_{eff}\rvert > \lvert Y_{eff}\rvert$	$\lvert X_{eff}\rvert < \lvert Y_{eff}\rvert$	-	-	$\lvert X_{eff}\rvert < \lvert Y_{eff}\rvert$	$\lvert X_{eff}\rvert > \lvert Y_{eff}\rvert$
SG (%)	0< SG <100	SG > 100	SG < 0	SG < 0	SG > 100	0< SG < 100
SI (coeff.)	SI > 1	0 < SI < 1	SI < 0	SI < 0	0 < SI < 1	SI > 1
Performance	unsustainable	sustainable	sustainable	unsustainable	unsustainable	quasi-sustainable
Corrective action 1	Intensity decrease	(Activity increase)	(Activity increase)	Intensity decrease	Intensity decrease	(Intensity increase)
Corrective action 2	Activity decrease	(Intensity increase)	(Intensity increase,)	Activity decrease	Activity decrease	(Activity increase)

Sustainability performance of the case companies

Stora Enso

The first case company is Stora Enso, an originally Finnish forest company. For industrial companies, energy consumption, raw material consumption and environmental impacts are significant variables to be taken into consideration when sustainability performance is analysed. Stora Enso's publicly available data includes all these variables at the aggregated consortium level. For calculation of the sustainability performance indicators SG and SI, the following six choices were made:

- V = total fuel consumption (EN), X = use of wood (RM); Table 2
- V = total fuel consumption (EN), X = paper and cardboard production (PROD); Table 3
- V = use of wood (RM), X = paper and cardboard production (PROD); Table 4
- V = CO_2 emissions (ES), X = total fuel consumption (EN); Table 5
- V = CO_2 emissions (ES), X= wood use (RM); Table 6
- V = CO_2 emissions (ES), X = paper and cardboard production (PROD); Table 7

Decomposition analysis and calculation of the sustainability performance indicators SG and SI were carried out for annual changes between the years 2010-2016 (moving base year, yellow background) and for cumulative changes during the same period (fixed base year 2010, pink background). Tables 2-7 show results from these decompositions for Stora Enso.

In each table, the first row includes the intensity effect, second row shows the activity effect, third row is the sum of these two effects, i.e. the change of the decomposed variable V. The intensity and activity effect and the sum are presented as percentage (%) from the reference year's absolute value of the decomposed variable V. The reference value in incremental analysis (yellow background) is the previous year's value and in the cumulative analysis (pink background) the fixed value of the year 2010). Fourth row shows the SG value (in percentage from the observed activity change ΔX), and fifth row shows the coefficient value of SI. The sustainable intensity can be calculated by multiplying the calculated intensity effect (first row) with the calculated coefficient value. The last row shows in which case (B1-B6) the incremental or cumulative performance belongs to. As noted above, cases B2, B3 and B6 are sustainable and cases B1, B4 and B5 are unsustainable (Figure 4).

Analysis of energy consumption

In the first analysis, Stora Enso's energy consumption (measured with total fuel consumption) is explained by use of wood, the major raw material. Table 2 shows that in the studied periods the intensity effect (energy intensity of wood use) has either decreased or increased energy consumption depending on the period, but the activity effect (wood use) has mostly decreased it. As a result, energy consumption has decreased in most of the incremental periods and in all cumulative periods. The most common cases are B3 and B6, both sustainable. The only unsustainable ones (B5) are incremental periods 2012-2013 and 2015-2016. Stora Enso's performance with this pair of indicators is sustainable in the cumulative analysis, but this is a result of the activity effect (decreasing use of wood). What is behind this, is the most interesting question, which, however, goes beyond this analysis and requires further research.

Table 2. Sustainability performance indicators SG and SI for Stora Enso's energy consumption, incremental and cumulative performance 2010-2016. V = EN = total fuel use, X = RM = use of wood.

ASA EN	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2010-11	2010-12	2010-13	2010-14	2010-15	2010-16
EN/RM	-0.59	-0.55	1.91	4.25	-5.51	3.30	-0.59	-1.14	0.74	4.94	-0.58	2.60
RM	-1.12	-1.13	-0.87	-5.03	1.78	-0.91	-1.12	-2.23	-3.10	-8.07	-6.16	-7.12
Total (ΔEN)	-1.71	-1.69	1.04	-0.78	-3.73	2.39	-1.71	-3.37	-2.36	-3.13	-6.75	-4.52
SG percentage	-52.98	-48.97	219.95	84.42	309.75	361.57	-52.98	-50.97	23.77	61.20	-9.48	36.52
SI coefficient	-1.92	-2.08	0.45	1.19	0.34	0.27	-1.92	-2.03	4.31	1.69	-11.31	2.87
Case	B3	B3	B5	B6	B2	B5	B3	B3	B6	B6	B3	B6

The second analysis for Stora Enso's energy consumption explains energy consumption (total fuel use) by energy intensity of production (intensity effect), but activity is now measured with paper and cardboard production (activity effect). The results in Table 3 resemble the previous ones (Table 2). The intensity effect mostly increases energy consumption, and activity effect decreases it in all incremental and cumulative periods. B6 is the most common case, and the only unsustainable periods (B5) are the same as in the previous analysis, incremental periods 2012-2013 and 2015-2016. With this pair of indicators, Stora Enso's performance is also sustainable, because paper and cardboard production has continuously decreased during the years 2010-2016. Further analysis of this international forest company's performance would find possible reasons for this.

Table 3. Sustainability performance indicators for Stora Enso's energy consumption, incremental and cumulative analysis 2010-2015. V = EN = total fuel consumption, X = PROD = paper and cardboard production (pulp and wood products not included).

ASA EN	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2010-11	2010-12	2010-13	2010-14	2010-15	2010-16
EN/PROD	2.31	-1.09	6.31	5.33	-0.01	5.96	2.31	1.21	7.43	12.70	12.47	18.46
PROD	-4.03	-0.60	-5.27	-6.12	-3.72	-3.57	-4.03	-4.58	-9.79	-15.83	-19.22	-22.98
Total (ΔEN)	-1.71	-1.69	1.04	-0.78	-3.73	2.39	-1.71	-3.37	-2.36	-3.13	-6.75	-4.52
SG percentage	57.42	-182.81	119.82	87.17	-0.30	166.84	57.42	26.40	75.86	80.23	64.90	80.34
SI coefficient	1.77	-0.56	0.83	1.16	-343.48	0.59	1.77	3.92	1.35	1.29	1.65	1.30
Case	B6	B3	B5	B6	B3	B5	B6	B6	B6	B6	B6	B6

Analysis of use of raw materials

In the third analysis, Stora Enso's use of major raw material, wood, is explained by material intensity of production (intensity effect) and paper and cardboard production (activity effect). Not surprisingly, results in Table 4 shows that the performance is sustainable because production has decreased. The intensity effect has mostly increased wood use, which may indicate a switch towards products with less additional raw materials. The problem in this analysis is that all products are not included, e.g. wood products and market pulp have been excluded.

Table 4. Sustainability performance indicators for Stora Enso's material consumption, incremental and cumulative analysis 2010-2015. V = RM = wood use, X = PROD = paper and cardboard production (pulp and wood products not included).

ASA RM	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2010-11	2010-12	2010-13	2010-14	2010-15	2010-16
RM/PROD	2.91	-0.54	4.36	1.06	5.66	2.62	2.91	2.36	6.67	7.56	13.10	15.63
PROD	-4.04	-0.60	-5.22	-5.98	-3.83	-3.51	-4.04	-4.61	-9.76	-15.42	-19.28	-22.65
Total (ΔRM)	-1.12	-1.14	-0.86	-4.93	1.83	-0.90	-1.12	-2.25	-3.09	-7.87	-6.18	-7.02
SG percentage	72.17	-89.84	83.48	17.67	147.78	74.44	72.17	51.25	68.33	49.00	67.95	68.99
SI coefficient	1.40	-1.13	1.21	5.95	0.66	1.36	1.40	2.00	1.51	2.22	1.57	1.56
Case	B6	B3	B6	B6	B5	B6	B6	B6	B6	B6	B6	B6

Analysis of environmental impacts

Tables 5-7 show results from the analysis of Stora Enso's environmental impacts measured with direct carbon dioxide emissions (CO_2) in all three analyses. CO_2 emissions are explained by energy use (Table 5), use of wood (Table 6) and production of paper and cardboard (Table 7). Analyses of the cumulative periods are similar in all Tables 5-7. Both intensity effect and activity effect have decreased CO_2 emissions in all periods, which represent the sustainable case B3 (which is common also in the incremental analyses). The cumulative SG and SI values are negative, and their self-values indicate that both activity and intensity could be increased quite a lot, without threatening sustainability, i.e. keeping CO_2 emissions below the reference level.

Table 5. Sustainability performance indicators for Stora Enso's environmental impacts, incremental and cumulative analysis 2010-2015. V = ES = direct CO_2 emissions, X = EN = total fuel use.

ASA ES	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2010-11	2010-12	2010-13	2010-14	2010-15	2010-16
ES/EN	-15.20	-1.20	2.80	-2.65	-6.75	-0.73	-15.20	-16.09	-13.87	-16.07	-21.34	-22.13
EN	-1.58	-1.68	1.06	-0.77	-3.60	2.38	-1.58	-3.10	-2.20	-2.87	-6.00	-4.01
Total (ΔES)	-16.79	-2.88	3.86	-3.43	-10.36	1.65	-16.79	-19.18	-16.07	-18.94	-27.34	-26.14
SG percentage	-960.84	-71.76	-264.41	-342.99	-187.34	30.66	-960.84	-519.46	-630.90	-559.06	-355.59	-552.42
SI coefficient	-0.13	-1.43	-0.36	-0.30	-0.60	3.21	-0.13	-0.24	-0.19	-0.22	-0.39	-0.25
Case	B3	B3	B4	B3	B3	B1	B3	B3	B3	B3	B3	B3

Table 6. Sustainability performance indicators for Stora Enso's environmental impacts, incremental and cumulative analysis 2010-2015. V = ES = direct CO_2 emissions, X = RM = use of wood.

ASA ES	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2010-11	2010-12	2010-13	2010-14	2010-15	2010-16
ES/RM	-15.75	-1.76	4.74	1.54	-12.07	2.56	-15.75	-17.13	-13.18	-11.55	-21.86	-19.84
RM	-1.03	-1.13	-0.88	-4.97	1.72	-0.91	-1.03	-2.05	-2.88	-7.39	-5.48	-6.30
Total (ΔES)	-16.79	-2.88	3.86	-3.43	-10.36	1.65	-16.79	-19.18	-16.07	-18.94	-27.34	-26.14
SG percentage	-1522.52	-155.86	537.07	30.96	702.10	281.39	-1522.52	-834.69	-457.31	-156.28	-398.60	-314.87
SI coefficient	-0.08	-0.66	0.18	3.34	0.16	0.35	-0.08	-0.15	-0.26	-0.79	-0.35	-0.43
Case	B3	B3	B5	B6	B2	B5	B3	B3	B3	B3	B3	B3

Table 7. Sustainability performance indicators for Stora Enso's environmental impacts, incremental and cumulative analysis 2010-2015. V = ES = direct CO_2 emissions, X = PROD = paper and cardboard production (pulp and wood products not included).

ASA ES	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2010-11	2010-12	2010-13	2010-14	2010-15	2010-16
ES/PROD	-13.07	-2.29	9.20	2.60	-6.76	5.21	-13.07	-14.98	-6.99	-4.49	-10.38	-6.01
PROD	-3.71	-0.59	-5.34	-6.03	-3.59	-3.56	-3.71	-4.21	-9.08	-14.46	-16.96	-20.13
Total (ΔES)	-16.79	-2.88	3.86	-3.43	-10.36	1.65	-16.79	-19.18	-16.07	-18.94	-27.34	-26.14
SG percentage	-352.09	-385.73	172.18	43.16	-188.21	146.35	-352.09	-356.16	-76.95	-31.03	-61.18	-29.83
SI coefficient	-0.34	-0.27	0.56	2.40	-0.59	0.67	-0.34	-0.35	-1.55	-3.98	-2.25	-4.54
Case	B3	B3	B5	B6	B3	B5	B3	B3	B3	B3	B3	B3

ENEL

The second case company is ENEL, an Italian energy company. For energy companies, raw material (primary energy) consumption, environmental impacts and production of energy carriers are significant variables to be taken into consideration when the sustainability performance is analysed. ENEL's publicly available data includes all these variables for the aggregated consortium level. Primary energy use and electricity production are available for specific primary energy sources, such as coal, oil and gas, uranium, renewables, geothermal, and biomass.

For calculation of the sustainability performance indicators SG and SI, the following nine choices were made:

- V = total fuel use (RM), X = total electricity production (PROD); Table 8
- V = use of coal (RM), X = electricity production from coal (PROD); Table 9
- V = use of oil and natural gas (RM), X = electricity production from oil and natural gas (PROD); Table 10
- V = use of renewables (RM), X = electricity production from renewables (PROD); Table 11
- V = use of geothermal (RM), X = electricity production from geothermal (PROD); Table 12
- V = use of biomass (RM), X = electricity production from biomass (PROD); Table 13
- V = CO_2 emissions (ES), X = total fuel use (RM); Table 14
- V = CO_2 emissions (ES), X= total electricity production (PROD); Table 15

Decomposition analysis and calculation of the sustainability performance indicators SG and SI were carried out for annual changes between the years 2010-2015 (moving base year) and for cumulative changes during the same period (fixed base year 2010). Tables 8-15 show results from these decompositions. In each table, the first row includes the intensity effect, second row shows the activity effect and third row is the sum of the effects, i.e. the change of the decomposed variable V. The intensity and activity effect and the sum are presented as percentage (%) from the reference year's absolute value of the decomposed variable V. The reference value in incremental analysis (yellow background) is the previous year's value and in the cumulative analysis (pink background) the fixed value of the year 2010). Fourth row shows the SG value (in percentage from the observed activity change ΔX), and fifth row shows the coefficient value of SI. The sustainable intensity can be calculated by multiplying the calculated intensity effect (first row) with the calculated coefficient value. The last row shows in which case (B1-B6) the incremental or cumulative performance belongs to. As noted above, cases B2, B3 and B6 are sustainable and cases B1, B4 and B5 are unsustainable.

Analysis of use of raw materials (primary energy)

ENEL's raw materials are primary energy sources. Performance in the use of aggregated primary energy, measured with total fuel use, is analysed in Table 8. Total fuel use is explained by primary energy intensity of electricity production (intensity effect) and total electricity production (activity effect). The results show that energy intensity has mostly increased fuel use, only incremental periods 2012-13 and 2013-2014 are exceptions of this. Activity effect has decreased fuel use in the incremental period 2012-2013, and in all cumulative periods after that. However, fuel use has increased in all cumulative periods, so ENEL's primary energy use has been unsustainable (there are two incremental exceptions, periods 2012-2013 and 2013-2014. Cumulative SG and SI values are first negative (case B4), and then turn to positive (case B5) with self-values indicating that changes required for sustainability are remarkable.

Table 8. Sustainability performance indicators SG and SI for ENEL's primary energy use, incremental and cumulative analysis, 2010-2015. V = RM = total fuel use, X = PROD = total electricity production.

ASA RM	2010-11	2011-12	2012-13	2013-14	2014-15	2010-11	2010-12	2010-13	2010-14	2010-15
RM/PROD	32.97	0.92	-5.18	-5.95	5.59	32.97	34.26	26.51	19.13	25.75
PROD	1.48	0.32	-4.31	0.46	0.33	1.48	1.87	-3.29	-2.68	-2.41
Total (ΔRM)	34.46	1.24	-9.49	-5.49	5.92	34.46	36.13	23.22	16.45	23.34
SG percentage	-2222	-290	-120	1307	-1709	-2222	-1834	805	713	1067
SI coefficient	-0.03	-0.34	-0.92	0.08	-0.06	-0.03	-0.04	0.10	0.12	0.08
Case	B4	B4	B3	B2	B4	B4	B4	B5	B5	B5

Tables 9-13 show the results from ENEL's sustainability performance in the use of different primary energy sources. The use of each primary energy source is explained by energy intensity of electricity production (intensity effect) and electricity production from different energy sources (activity effect). Primary energy sources include coal (Table 9), oil and gas (Table 10), renewable energies (Table 11), geothermal energy (Table 12) and biomass (Table 13). For all primary energy source, the analysis covers the years 2010-2015 except uranium, where analysis covers the years 2011-2015 due to availability of data.

ENEL's use of coal has been unsustainable except the incremental period 2012-2013, when electricity production from coal decreased (Table 9). Energy intensity of coal-fired electricity production has not improved since 2010-2011. Since then the intensity effect has slightly increased coal use, but all cumulative periods fall into case B1 with low positive values for SG and high positive values for SI. The use of coal is more dependent on the amount of produced electricity, which is not surprising assuming that there are no significant changes in the coal-fired power plant capacity during the relatively short (5 years) studied period.

Table 9. Sustainability performance indicators SG and SI for ENEL's primary energy use, incremental and cumulative analysis, 2010-2015. V = RM = use of coal, X = PROD = electricity production from coal.

ASA RM	2010-11	2011-12	2012-13	2013-14	2014-15	2010-11	2010-12	2010-13	2010-14	2010-15
RM/PROD	-4.2	1.2	1.4	0.6	0.5	-4.2	-3.2	-1.4	-0.7	-0.2
PROD	17.4	6.6	-11.6	1.0	4.5	17.4	25.1	11.0	12.1	17.2
Total (ΔRM)	13.2	7.7	-10.1	1.6	5.0	13.2	22.0	9.6	11.4	16.9
SG percentage	24	-18	12	-67	-11	24	13	13	6	1
SI coefficient	3.65	-5.30	9.03	-1.48	-8.81	3.65	6.53	7.15	14.63	58.99
Case	B1	B4	B6	B4	B4	B1	B1	B1	B1	B1

ENEL's use of gas and oil has first increased 2010-2011, then decreased 2011-2014 and increased again 2014-2015 (Table 10). The amount of produced electricity has dominated the performance, but in the most recent periods (2013-2014 and 2014-2015), the intensity effect has contributed more to the use of oil and gas than the activity effect. In the incremental analysis, ENEL's performance during the years 2011-2014 was sustainable in the use of oil and gas, but turned into unsustainable in the most recent period 2014-2015. In the cumulative analysis, ENEL's performance has been sustainable because of decreasing electricity production from oil and gas during the years 2011-2014.

Table 10. Sustainability performance indicators SG and SI for ENEL's primary energy use, incremental and cumulative analysis, 2010-2015. V = RM = use of oil and gas, X = PROD = electricity production from oil and gas.

ASA RM	2010-11	2011-12	2012-13	2013-14	2014-15	2010-11	2010-12	2010-13	2010-14	2010-15
RM/PROD	-0.8	1.4	-0.6	-5.6	7.8	-0.8	0.6	-0.024	-5.2	1.4
PROD	2.3	-8.7	-11.9	-2.5	3.4	2.3	-6.6	-17.7	-19.2	-17.3
Total (ΔRM)	1.4	-7.3	-12.5	-8.1	11.2	1.4	-6.0	-17.7	-24.4	-15.9
SG percentage	37	16	-5	-229	-232	37	9	-0.137	-27	8
SI coefficient	2.64	6.64	-22.22	-0.47	-0.39	2.64	11.50	-888.70	-4.92	14.79
Case	B1	B6	B3	B3	B4	B1	B6	B3	B3	B6

Table 11 shows the results of ENEL's performance in the use of renewable energies. One could argue that use of renewables is always sustainable, but efficient use of renewable energy sources is not a bad thing. In the light of sustainability performance indicators, the use of renewable energies has been mostly sustainable (case B2 in incremental and cases B6 and B3 in cumulative analyses). Incremental periods 2010-2011 and 2014-2015, as well as cumulative periods 2010-2011 and 2011-2012 fall in the unsustainable case B5, where intensity effect increases the use of renewables more than the activity effect (decreased electricity production) decreases it. In the period 2013-2014, there has been a significant decreasing contribution of the intensity effect to the use of renewables in ENEL. Table 11 is a good example of the importance of not looking at the SG and SI values alone. Next two renewable energy sources, geothermal (Table 12) and biomass (Table 13) are analysed separately.

Table 11. Sustainability performance indicators SG and SI for ENEL's primary energy use, incremental and cumulative analysis, 2010-2015. V = M = use of renewables, X = PROD = electricity production from renewables.

ASA RM	**2010-11**	**2011-12**	**2012-13**	**2013-14**	**2014-15**	**2010-11**	**2010-12**	**2010-13**	**2010-14**	**2010-15**
RM/PROD	14.02	-3.16	-9.88	-42.08	6.80	14.02	10.65	0.67	-41.44	-36.13
PROD	-11.05	0.96	8.72	3.15	-6.11	-11.05	-9.94	-1.13	2.22	-2.68
Total (ΔRM)	2.97	-2.20	-1.15	-38.94	0.68	2.97	0.71	-0.46	-39.22	-38.80
SG percentage	127	329	113	1338	111	127	107	60	1864	-1350
SI coefficient	0.77	0.31	0.89	0.12	0.89	0.77	0.93	1.68	0.09	-0.12
Case	B5	B2	B2	B2	B5	B5	B5	B6	B2	B3

ENEL's performance in electricity production from geothermal is analysed in Table 12. There is a significant drop in primary geothermal energy use in 2013-2014, which may be an improvement in technology, or a data problem[2]. In all studied periods, intensity effect has decreased the use of geothermal energy, and activity effect has increased it (except in 2011-2012).

Table 12. Sustainability performance indicators SG and SI for ENEL's primary energy use, incremental and cumulative analysis, 2010-2015. V = RM = use of geothermal energy, X = PROD = electricity production from geothermal.

ASA RM	**2010-11**	**2011-12**	**2012-13**	**2013-14**	**2014-15**	**2010-11**	**2010-12**	**2010-13**	**2010-14**	**2010-15**
RM/PROD	-3.10	-0.17	-2.31	-45.12	-3.26	-3.10	-3.24	-5.54	-49.59	-52.54
PROD	5.57	-1.93	1.60	5.22	4.15	5.57	3.56	5.16	9.46	12.94
Total (ΔRM)	2.47	-2.10	-0.70	-39.90	0.88	2.47	0.32	-0.38	-40.13	-39.60
SG percentage	56	-9	144	864	79	56	91	107	524	406
SI coefficient	1.75	-11.67	0.70	0.19	1.26	1.75	1.10	0.93	0.32	0.41
Case	B1	B3	B2	B2	B1	B1	B1	B2	B2	B2

In Table 13, performance of ENEL's electricity production from biomass is analysed. There is large annual variation in the intensity and activity effect, so the results are difficult to interpret. However, the use of biomass has not been increasing after 2011, and this seems to be a major reason for the sustainability of biomass use (case B6 in the cumulative analysis) for electricity production in ENEL. In the first incremental period 2010-2011, there was no change in electricity production from biomass, and the activity effect remains as zero. Calculation of the sustainability performance indicators SG and

[2] There is no information available how the amount of primary geothermal energy has been measured or estimated in ENEL. The practice of IEA statistics is multiplying the amount of produced geothermal electricity by a coefficient 10.

SI suffer from a zero value problem in situations, where the intensity or/and activity effects have no contribution to the decomposed variable.

Table 13. Sustainability performance indicators SG and SI for ENEL's primary energy use, incremental and cumulative analysis, 2010-2015. V = RM = use of Biomass, X = PROD = electricity production from biomass.

ASA RM	2010-11	2011-12	2012-13	2013-14	2014-15	2010-11	2010-12	2010-13	2010-14	2010-15
RM/PROD	11.20	-10.93	17.68	85.91	-39.72	11.20	-0.54	17.67	110.44	59.26
PROD	0.00	6.95	-25.10	-109.49	37.86	0.00	7.31	-18.83	-134.91	-85.13
Total (ΔRM)	11.20	-3.99	-7.43	-23.58	-1.86	11.20	6.77	-1.16	-24.47	-25.87
SG percentage		157	70	78	105		7	94	82	70
SI coefficient	0.00	0.66	1.53	1.67	0.97	0.00	13.41	1.07	2.04	2.38
Case		B2	B6	B6	B2		B1	B6	B6	B6

Analysis of environmental impacts

The performance of ENEL in relation to environmental impacts of activity was analysed by using carbon dioxide emissions (CO_2) as a decomposed variable. Activity was measured by two variables, first by total fuel use (Table 14) and then by total electricity production (Table 15). ENEL's performance has been in the edge of sustainability when CO_2 emissions are considered. During the studied period 2010-2015, CO_2 emissions have been slightly increasing. A major drop was in 2012-2014. The cumulative analysis in Table 14 shows that the intensity effect has decreased emissions slightly less than the activity effect (total fuel use) has increased them. Table 15 reveals that in cumulative analysis, intensity effect has not been able to decrease CO_2 emissions, so the decreasing effects have come from decreased electricity production only. However, incremental analysis shows that there have been some periods when intensity effect has decreased emissions (In Table 14 with total fuel use as activity, 2010-2011, 2012-2103, and 2014-2015; in Table 15 with electricity production as activity, 2012-2013 and 2013-2014.

Table 14. Sustainability performance indicators SG and SI for ENEL's environmental impacts, incremental and cumulative analysis, 2010-2015. V = ES = CO_2 emissions, X = RM = total fuel use.

ASA ES	2010-11	2011-12	2012-13	2013-14	2014-15	2010-11	2010-12	2010-13	2010-14	2010-15
ES/RM	-24.70	2.22	-0.10	5.59	-2.36	-24.70	-22.83	-21.68	-16.01	-18.70
RM	30.83	1.26	-9.48	-5.65	5.85	30.83	32.64	20.96	15.23	21.38
Total (ΔES)	6.12	3.47	-9.59	-0.06	3.49	6.12	9.81	-0.71	-0.78	2.69
SG percentage	80	-176	-1	99	40	80	70	103	105	87
SI coefficient	1.18	-0.55	-100.03	1.01	2.39	1.18	1.30	0.97	0.96	1.11
Case	B1	B4	B3	B6	B1	B1	B1	B2	B2	B1

Table 15. Sustainability performance indicators SG and SI for ENEL's environmental impacts, incremental and cumulative analysis, 2010-2015. V = ES = CO_2 emissions, X = PROD = total electricity production.

ASA ES	2010-11	2011-12	2012-13	2013-14	2014-15	2010-11	2010-12	2010-13	2010-14	2010-15
ES/PROD	4.82	3.15	-5.28	-0.53	3.17	4.82	8.15	2.22	1.69	4.88
PROD	1.31	0.32	-4.31	0.47	0.32	1.31	1.66	-2.93	-2.47	-2.19
Total (ΔES)	6.12	3.47	-9.59	-0.06	3.49	6.12	9.81	-0.71	-0.78	2.69
SG percentage	-369	-977	-122	113	-979	-369	-491	76	69	223
SI coefficient	-0.26	-0.10	-0.90	0.89	-0.10	-0.26	-0.19	1.33	1.47	0.44
Case	B4	B4	B3	B2	B4	B4	B4	B6	B6	B5

RWE

The first case company is RWE, a German energy company. For energy companies, raw material (primary energy) consumption, environmental impacts and production of energy carriers are significant variables to be taken into consideration when the sustainability performance is analysed. RWE's publicly available data includes all these variables for the aggregated consortium level. Data on primary energy consumption and production of energy carriers is available also for three fuel categories: lignite, hard coal, and oil and natural gas.

For calculation of the sustainability performance indicators SG and SI, the following 12 choices were made:

- V = total fuel consumption (RM), X = total electricity production (PROD); Table 16
- V = use of lignite (RM), X = electricity production from lignite (PROD); Table 17
- V = use of hard coal (RM), X = electricity production from hard coal (PROD); Table 18
- V = use of oil and natural gas (RM), X = electricity production from oil and natural gas (PROD); Table 19
- V = CO_2 emissions (ES), X = total fuel consumption (RM); Table 20
- V = CO_2 emissions (ES), X= total electricity production (PROD); Table 21
- V = NO_x emissions from lignite (ES), X = use of lignite (RM); Table 22
- V = SO_2 emissions from lignite (ES), X = use of lignite (RM); Table 23
- V = NO_x emissions from hard coal (ES), X = use of hard coal (RM); Table 24
- V = SO_2 emissions from hard coal (ES), X = use of hard coal (RM); Table 25
- V = NO_x emissions from oil and natural gas (ES), X = use of oil and natural gas (RM); Table 26
- V = SO_2 emissions from oil and natural gas (ES), X = use of oil and natural gas (RM); Table 27

Decomposition analysis and calculation of the sustainability performance indicators SG and SI were carried out for annual changes between the years 2010-2016 (moving base year) and for cumulative changes during the same period (fixed base year 2010). Data of CO_2 emissions was available for the period 2010-2015 only.

Tables 16-27 show results from the decompositions and indicator calculations for RWE. In each table, the first row includes the intensity effect, second row shows the activity effect and third row is the sum of the effects, i.e. the change of the decomposed variable V. The intensity and activity effect and the sum are presented as percentage (%) from the reference year's absolute value of the decomposed variable V. The reference value in incremental analysis (yellow background) is the previous year's value and in the cumulative analysis (pink background) the fixed value of the year 2010). Fourth row shows the SG value (in percentage from the observed activity change ΔX), and fifth row shows the coefficient value of SI. The sustainable intensity can be calculated by multiplying the calculated intensity effect (first row) with the calculated coefficient value. The last row shows in which case (B1-B6) the incremental or cumulative performance belongs to. As noted above, cases B2, B3 and B6 are sustainable and cases B1, B4 and B5 are unsustainable.

Analysis of use of raw materials (primary energy)

RWE's performance in the use of raw materials has been analysed by using primary energy as a decomposed variable. There are several analyses, first total primary energy use has been analysed (Table 16) and then different primary energy sources separately: lignite (Table 17), hard coal (Table 18), and oil and gas (Table 19). Activity is measured with electricity production. The data on electricity production is available by energy source in the very useful data application in the RWE website.

RWE's performance in primary energy use is analysed in Table 16. The use of primary energy has both increased and decreased annually during the period 2010-2016. This can be seen also in the cumulative figures. In the incremental analysis, the intensity effect has increased primary energy use in four periods and decreased in two periods (2012-2013 and 2015-2016) only. The activity effect has contribute relatively more to primary energy use, and the activity effect has been an increasing or decreasing one depending on the period. In the cumulative analysis, the intensity effect has increased primary energy use and the activity effect decreased it throughout the whole studied period, the only exception is the period 2010-2012. In general, the performance of RWE has been mostly unsustainable with this pair of variables.

Table 16. Sustainability performance indicators SG and SI for RWE's primary energy use, incremental and cumulative analysis, 2010-2016. V = RM = use of primary energy, X = PROD = total electricity production.

ASA RM	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2010-11	2010-12	2010-13	2010-14	2010-15	2010-16
RM/PROD	5.86	1.13	-2.11	0.55	1.33	-0.70	5.86	7.30	4.88	5.34	6.75	6.07
PROD	-8.97	10.46	-3.88	-4.55	2.27	1.45	-8.97	0.83	-3.23	-7.75	-5.65	-4.21
Tiotal (ΔRM)	-3.10	11.59	-5.99	-4.00	3.60	0.75	-3.10	8.13	1.65	-2.41	1.10	1.86
SG percentage	65	-11	-55	12	-59	48	65	-882	151	69	120	144
SI coefficient	1.58	-8.27	-1.95	8.62	-1.65	2.05	1.58	-0.10	0.65	1.49	0.83	0.68
Case	B6	B4	B3	B6	B4	B1	B6	B4	B5	B6	B5	B5

Tables 17-19 show the results of RWE's sustainability performance in the use of lignite, hard coal and gas and oil, correspondingly. In these tables, activity is measured with electricity production from each primary energy source. In cumulative analysis, lignite use has been above the 2010 level during the studied period (Table 17). Incremental analysis shows that lignite use has decreased in three periods, 2012-2013, 2013-2014 and 2015-2016. The performance is mostly unsustainable. Major reason for this is that the intensity effect has not been able to decrease lignite use, this has happened only in two incremental periods, 2013-2014 and 2015-2016. The activity effect has decreased lignite use in two periods, 2011-2012 and 2012-2013 (Table 17). These decreases have a reflection to the cumulative analysis, activity effect has decreased lignite use from the period 2010-2012 onwards and the SG values are high. The interpretation is that the decrease in lignite use should be several times larger than the observed one, because the lignite intensity of electricity production has increased.

Table 17. Sustainability performance indicators SG and SI for RWE's primary energy use, incremental and cumulative analysis, 2010-2016. V = RM = use of lignite, X = PROD = electricity production from lignite.

ASA RM	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2010-11	2010-12	2010-13	2010-14	2010-15	2010-16
RM/PROD	4.38	9.18	0.24	-5.02	0.78	-4.50	4.38	13.92	13.89	8.60	9.48	4.60
PROD	0.59	-3.07	-4.41	3.78	1.00	0.18	0.59	-2.54	-7.15	-3.18	-2.18	-1.95
Total (ΔRM)	4.97	6.11	-4.17	-1.24	1.78	-4.33	4.97	11.38	6.74	5.41	7.29	2.65
SG percentage	-738	299	5	133	-78	2539	-738	549	194	270	434	236
SI coefficient	-0.13	0.32	19.05	0.76	-1.26	0.04	-0.13	0.16	0.48	0.35	0.21	0.41
Case	B4	B5	B6	B2	B4	B2	B4	B5	B5	B5	B5	B5

Table 18 shows the results from RWE's performance in the use of hard coal. I cumulative terms, hard coal use has slightly increased since 2011, but annual (incremental) changes are relatively large, decreasing or increasing, depending on the period. In 2013-2014 there was no change in hard coal use. The performance has been mostly unsustainable, but intensity effect has decreased hard coal use in all incremental periods except 2011-2012. This the most common case of performance is B1 in the cumulative analysis, 51-80 % of hard coal use has been sustainable.

Table 18. Sustainability performance indicators SG and SI for RWE's primary energy use, incremental and cumulative analysis, 2010-2016. V = RM = use of hard coal, X = PROD = electricity production from hard coal.

ASA RM	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2010-11	2010-12	2010-13	2010-14	2010-15	2010-16
RM/PROD	-13.16	28.46	-14.28	-7.39	-4.08	-4.65	-13.16	10.20	-6.08	-13.64	-18.94	-23.25
PROD	-3.36	14.25	1.14	7.39	18.36	-3.44	-3.36	8.93	9.56	17.12	37.20	31.94
Total (ΔRM)	-16.52	42.71	-13.14	0.00	14.29	-8.09	-16.52	19.13	3.48	3.48	18.26	8.70
SG percentage	-392	-200	1253	100	22	-135	-392	-114	64	80	51	73
SI coefficient	-0.31	-0.35	0.09	1.00	3.94	-0.81	-0.31	-0.74	1.52	1.21	1.66	1.26
Case	B3	B4	B2	B1	B1	B3	B3	B4	B1	B1	B1	B1

Table 19 shows the results from RWE's performance in the use of gas and oil. Use of gas and oil has first decreased annually but after 2014 turned to increase. As a result, it has remained below the 2010 level during the studied period, except the last cumulative period 2010-2016 (Table 19). The performance has been often sustainable (cases B2, B3 and B6), but the intensity effect has decreased gas and oil use in two incremental periods only, in 2010-2011 and 2012-2013. In all other incremental periods, the activity effect has decreased gas and oil use. Because of large increase caused by the intensity effect in 2014-2015 and 2015-2016, the most recent performance falls into the unstainable case B5.

Table 19. Sustainability performance indicators SG and SI for RWE's primary energy use, incremental and cumulative analysis, 2010-2016. V = RM = use of oil and natural gas, X = PROD = electricity production from oil and natural gas.

ASA RM	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2010-11	2010-12	2010-13	2010-14	2010-15	2010-16
RM/PROD	-10.17	2.78	-6.75	3.43	10.79	24.98	-10.17	-7.37	-13.73	-10.41	-0.44	23.22
PROD	2.30	-5.22	5.50	-4.70	-8.23	-1.23	2.30	-2.74	2.50	-1.95	-9.67	-11.99
Total (ΔRM)	-7.87	-2.44	-1.25	-1.27	2.56	23.75	-7.87	-10.11	-11.24	-12.36	-10.11	11.24
SG percentage	441	53	123	73	131	2031	441	-269	550	-533	-5	194
SI coefficient	0.25	1.92	0.83	1.39	0.74	0.04	0.25	-0.41	0.20	-0.21	-24.19	0.46
Case	B2	B6	B2	B6	B5	B5	B2	B3	B2	B3	B3	B5

Analysis of environmental impacts

RWE's performance in environmental impacts is first analysed by using carbon dioxide emissions as decomposed variable and activity has been measured with total primary energy use (Table 20) and total electricity production (Table 21). Then emissions of nitrous oxides (NO_x) and sulphur dioxide (SO_2) from fossil fuel combustion have been analysed by measuring activity with lignite use (Tables 22 and 23), hard coal use (Tables 24 and 25) and oil and gas use (Tables 26 and 27, correspondingly). Data on CO_2 emissions was available for the years 2010-2015 only.

RWE's performance regrading CO_2 emissions shows that during the studied period, the intensity effect has decreased emissions when activity is measured by total primary energy use (Table 20). This refers to a change in fuel mix towards less carbon intensive fuels. In the incremental analysis, the activity effect has increased or decreased emissions, depending on the period. Cumulatively, CO_2 emissions have decreases especially during the two most recent years and the performance has fulfilled the relative sustainability criterion in the period 2012-2015.

When the activity is measured by electricity production, the performance of RWE in regard to CO_2 emissions is different, especially in the cumulative analysis (Table 21). The intensity effect is now weaker, and decrease in CO_2 emissions is more a result from decreasing activity, i.e. electricity production.

Table 20. Sustainability performance indicators SG and SI for RWE's environmental impacts, incremental and cumulative analysis, 2010-2015. V = ES = total CO_2 emissions, V = RM = total primary energy use.

ASA ES	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2010-11	2010-12	2010-13	2010-14	2010-15	2010-16
ES/RM	1.30	-0.51	-2.94	-1.34	-6.32		1.30	0.87	-2.24	-3.51	-9.60	
RM	-3.12	11.57	-5.90	-3.97	3.49		-3.12	8.17	1.64	-2.37	1.05	
Total (ΔES)	-1.82	11.06	-8.84	-5.31	-2.84		-1.82	9.04	-0.61	-5.88	-8.55	
SG percentage	42	4	-50	-34	181		42	-11	137	-148	914	
SI coefficient	2.44	20.46	-2.20	-3.14	0.57		2.44	-8.61	0.73	-0.72	0.12	
Case	B6	B1	B3	B3	B2		B5	B4	B2	B3	B2	

Table 21. Sustainability performance indicators SG and SI for RWE's environmental impacts, incremental and cumulative analysis, 2010-2015. V = ES = total CO_2 emissions, X = PROD = total electricity production.

ASA ES	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2010-11	2010-12	2010-13	2010-14	2010-15	2010-16
ES/PROD	7.21	0.62	-5.02	-0.79	-5.04		7.21	8.20	2.59	1.73	-3.18	
PROD	-9.03	10.43	-3.82	-4.52	2.20		-9.03	0.83	-3.19	-7.61	-5.37	
Total (ΔES)	-1.82	11.06	-8.84	-5.31	-2.84		-1.82	9.04	-0.61	-5.88	-8.55	
SG percentage	80	-6	-132	-17	229		80	-987	81	23	-59	
SI coefficient	1.28	-15.11	-0.83	-6.05	0.45		1.28	-0.09	1.24	4.67	-1.85	
Case	B6	B4	B3	B3	B2		B6	B4	B6	B6	B3	

Tables 22 and 23 show the results of RWE sustainability performance when environmental impact is measured by NO_x emissions from lignite use (Table 22) and SO_2 emissions from lignite use (Table 23), and activity is measured by the use of lignite.

In the incremental analysis, NO_x emissions have increased or decreased depending on the period (Table 22). Moreover, intensity and activity effect have either increased or decreased NO_x emissions, and the incremental performance has varied between sustainable and unsustainable. Cumulative analysis reveals that NO_x emissions have increased since 2010, mostly because of the intensity effect. The cumulative SG values for NO_x emissions are mostly negative and large (e.g. -799 % in 2010-2014), and the SI values negative and small. The SG values mean that instead of a small increasing effect, the activity effect should be negative and several times larger (e.g. eight times larger than the observed in 2010-2014), because the intensity effect has increased the emissions so much. The SI values, on the other hand, mean that the observed positive intensity effect should be negative in order to keep the use of lignite at a sustainable level.

Table 23 shows that in the incremental analysis, SO_2 emissions have biannually increased and biannually decreased. During the period 2010-2014, the change in SO_2 emissions has mostly followed the activity effect, i.e. use of lignite. In general, the performance of RWE in SO_2 emissions is quite similar to the performance in NO_x emissions in the case of lignite use. However, the SG and SI are mostly negative, but the self-value of SG is smaller and the self-value of SI is larger than in the case of NO_x emissions (cf. Tables 22 and 23).

Table 22. Sustainability performance indicators SG and SI for RWE's environmental impacts, incremental and cumulative analysis, 2010-2016. V = ES = NO_x emissions from lignite, X = RM = use of lignite.

ASA ES	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2010-11	2010-12	2010-13	2010-14	2010-15	2010-16
ES/RM	4.99	6.12	-4.24	-1.22	1.81	-4.24	4.99	11.45	6.89	5.43	7.42	2.65
RM	0.64	0.59	3.26	-3.71	2.70	-3.67	0.64	1.26	4.72	0.68	3.48	-0.52
Total (ΔES)	5.62	6.71	-0.98	-4.93	4.51	-7.91	5.62	12.71	11.61	6.11	10.90	2.13
SG percentage	-784	-1044	130	-33	-67	-116	-784	-908	-146	-799	-213	510
SI coefficient	-0.12	-0.09	0.78	-3.20	-1.43	-0.94	-0.12	-0.10	-0.61	-0.12	-0.42	0.19
Case	B4	B4	B2	B3	B4	B3	B4	B4	B4	B4	B4	B5

Table 23. Sustainability performance indicators SG and SI for RWE's environmental impacts, incremental and cumulative analysis, 2010-2016. V = ES = SO_2 emissions from lignite, X = RM = use of lignite.

ASA ES	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2010-11	2010-12	2010-13	2010-14	2010-15	2010-16
ES/RM	5.23	5.49	-4.75	-1.19	1.77	-4.26	5.23	10.71	7.18	5.50	7.37	2.64
RM	10.73	-20.77	27.64	-8.74	-1.00	-2.89	10.73	-12.47	13.54	3.23	2.21	-0.90
Total (ΔES)	15.96	-15.28	22.88	-9.93	0.78	-7.15	15.96	-1.76	20.72	8.73	9.58	1.74
SG percentage	-49	26	17	-14	178	-147	-49	86	-53	-170	-334	294
SI coefficient	-1.77	4.47	4.73	-8.17	0.56	-0.73	-1.77	1.19	-1.56	-0.54	-0.27	0.33
Case	B4	B6	B1	B3	B5	B3	B4	B6	B4	B4	B4	B5

RWE's sustainability performance of environmental impact of hard coal use is measured by NO_x emissions from hard coal use in Table 24, and by SO_2 emissions from hard coal use in Table 25.

There is large annual variation in the NO_x emissions, e.g. large increase in 2011-2012 and large decrease in 2013-2014 and 205-2016 (Table 24). Due to the decreases caused by the activity effect in 2013-2014, 2014-2015 and 2015-2016, the cumulative NO_x emissions have turned below the 2010 level after the year 2013. The intensity effect has decreased emissions in three periods, in 2010-2011, 2012-2013 and 2015-2016. In the period 2013-2014 there was no change in intensity, so the SI value could not be calculated. The annual SG and SI values vary a lot. In the cumulative analysis, the NOx emissions from hard coal use have decreased because of decreased activity, and the SG values are quite small. This means from the sustainability point of view, that the decrease in activity (hard coal use) has been larger than needed with the observed increase in intensity. On the other hand, the SI values tell that with the observed decrease in activity, the intensity effect could be even larger without threatening sustainability.

There is a large annual variation also in the SO_2 emissions, large increase in 2011-2012 and large decrease in 2013-2014 and 205-2016 (Table 25). The results are very similar to the NO_x emissions above. Most exceptions are in the incremental analysis. In the cumulative analysis there are differences in the self-values of the performance indicators SG and SI, the only significant difference is the period 2010-2014 where the indicator values for NO_x emissions are positive and for SO_2 emissions negative (cf. Tables 24 and 25).

Table 24. Sustainability performance indicators SG and SI for RWE's environmental impacts, incremental and cumulative analysis, 2010-2016. V = ES = NO_x emissions from hard coal, X = RM = use of hard coal.

ASA ES	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2010-11	2010-12	2010-13	2010-14	2010-15	2010-16
ES/RM	-18.14	42.70	-14.67	0.00	13.41	-6.36	-18.14	20.99	4.30	3.21	15.91	6.20
RM	17.94	-0.07	21.79	-42.62	-13.06	-40.97	17.94	21.35	48.18	-15.71	-28.10	-59.95
Total (ΔES)	-0.20	42.63	7.12	-42.62	0.35	-47.33	-0.20	42.35	52.48	-12.50	-12.19	-53.75
SG percentage	101	60631	67	0	103	-16	101	-98	-9	20	57	10
SI coefficient	0.99	0.00	1.39	#DIV/0!	0.97	-12.23	0.99	-0.71	-7.34	5.59	2.01	20.92
Case	B2	B5	B1	B3	B5	B3	B2	B4	B4	B6	B6	B6

Table 25. Sustainability performance indicators SG and SI for RWE's environmental impacts, incremental and cumulative analysis, 2010-2016. V = ES = SO_2 emissions from hard coal, X = RM = use of hard coal.

ASA ES	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2010-11	2010-12	2010-13	2010-14	2010-15	2010-16
ES/RM	-18.00	50.61	-13.52	0.00	11.90	-5.67	-18.00	25.02	4.71	3.57	15.55	5.58
RM	16.46	44.90	5.36	-38.30	-35.73	-57.28	16.46	67.47	72.08	5.50	-32.46	-74.80
Total (ΔES)	-1.54	95.51	-8.16	-38.30	-23.83	-62.95	-1.54	92.50	76.79	9.08	-16.91	-69.22
SG percentage	109	-113	252	0	33	-10	109	-37	-7	-65	48	7
SI coefficient	0.93	-0.45	0.43	#DIV/0!	3.94	-27.25	0.93	-1.40	-8.66	-1.41	2.51	43.55
Case	B2	B4	B2	B3	B6	B3	B2	B4	B4	B4	B6	B6

RWE's sustainability performance of environmental impact of the use of gas and oil analysed in Table 26 (NO_x emissions) and Table 27 (SO_2 emissions). Perhaps these analyses are not very relevant ones, but because there is data available, the analyses have been carried out. The cumulative results show that the NOx emissions from gas and oil use have been 15-35 % below the 2010 level during the studied period (Table 26). The cumulative SO_2 emissions from gas and oil use have also been below the 2010 level, except the period 2010-2014. The sustainability performance of RWE regarding NO_x and SO_2 emissions falls into different cases B1-B6 in all incremental analyses. In the cumulative analysis, there are similarities.

Table 26. Sustainability performance indicators SG and SI for RWE's environmental impacts, incremental and cumulative analysis, 2010-2016. V = ES = NO_x emissions from gas and oil, X = RM = use of gas and oil.

ASA ES	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2010-11	2010-12	2010-13	2010-14	2010-15	2010-16
ES/RM	-7.45	-2.51	-1.11	-1.30	2.60	23.17	-7.45	-9.83	-9.72	-10.91	-9.02	9.81
RM	-10.09	5.36	-22.44	4.81	2.45	-5.42	-10.09	-5.36	-25.44	-21.97	-20.48	-26.79
Total (ΔES)	-17.54	2.86	-23.55	3.51	5.05	17.76	-17.54	-15.19	-35.16	-32.89	-29.50	-16.98
SG percentage	-74	47	-5	27	-106	428	-74	-183	-38	-50	-44	37
SI coefficient	-1.64	2.08	-26.48	3.58	-0.90	0.20	-1.64	-0.64	-4.04	-3.00	-3.22	3.29
Case	B3	B1	B3	B1	B4	B5	B3	B3	B3	B3	B3	B6

Table 27. Sustainability performance indicators SG and SI for RWE's environmental impacts, incremental and cumulative analysis, 2010-2016. V = ES = SO_2 emissions from gas and oil, X = RM = use of gas and oil.

ASA ES	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2010-11	2010-12	2010-13	2010-14	2010-15	2010-16
ES/RM	-7.77	-2.51	-1.22	-1.96	1.56	20.88	-7.77	-10.26	-11.09	-18.80	-7.30	7.50
RM	-2.27	5.36	-5.35	108.99	-79.31	-27.04	-2.27	2.78	-2.46	97.77	-52.89	-70.15
Total (ΔES)	-10.05	2.86	-6.57	107.03	-77.75	-6.16	-10.05	-7.48	-13.55	78.97	-60.19	-62.64
SG percentage	-342	47	-23	2	2	77	-342	369	-450	19	-14	11
SI coefficient	-0.33	2.08	-4.71	26.86	228.54	1.38	-0.33	0.29	-0.26	2.91	-18.21	25.02
Case	B3	B1	B3	B1	B6	B6	B3	B2	B3	B1	B3	B6

Celsa Barcelona

The fourth case company is Celsa Barcelona, a Spanish/Catalan metal product company. For industrial companies, energy consumption, raw material consumption and environmental impacts are significant variables to be taken into consideration when the sustainability performance is analysed. Celsa Barcelona's publicly available data includes all these variables for the aggregated company level, and energy consumption and activity (production) data for four different product categories: steel billets, wires and rods, structural profiles, and steel plates.

For calculation of the sustainability performance indicators SG and SI, the following nine choices were made:

- V = total energy consumption (EN), X = total amount of metal products (PROD); Table 28
- V = energy consumption for steel billets (EN), X = production of steel billets (PROD); Table 29
- V = energy consumption for wires and rods (EN), X = production of wires and rods (PROD); Table 30
- V = energy consumption for structural profiles (EN), X = production of structural profiles (PROD); Table 31
- V = energy consumption for steel plates (EN), X = production of steel plates (PROD); Table 32
- V = use of scrap and steel alloys (RM), X = total amount of metal products (PROD); Table 33
- V = total CO_2 emissions (ES), X = total energy consumption (EN); Table 34
- V = total CO_2 emissions (ES), X= use of scrap and steel alloys (RM); Table 35
- V = total CO_2 emissions (ES), X = total production of metal products (PROD); Table 36

Decomposition analysis and calculation of the sustainability performance indicators SG and SI were carried out for annual changes between the years 2010-2015 (moving base year) and for cumulative changes during the same period (fixed base year 2010). Tables 28-36 show results from these decompositions. In each table, the first row includes the intensity effect, second row shows the activity effect and third row is the sum of the effects, i.e. the change of the decomposed variable V. The intensity and activity effect and the sum are presented as percentage (%) from the reference year's absolute value of the decomposed variable V. The reference value in incremental analysis (yellow background) is the previous year's value and in the cumulative analysis (pink background) the fixed value of the year 2010). Fourth row shows the SG value (in percentage from the observed activity change ΔX), and fifth row shows the coefficient value of SI. The sustainable intensity can be calculated by multiplying the calculated intensity effect (first row) with the calculated coefficient value. The last row shows in which case (B1-B6) the incremental or cumulative performance belongs to. As noted above, cases B2, B3 and B6 are sustainable and cases B1, B4 and B5 are unsustainable.

Analysis of energy consumption

Energy consumption of Celsa Barcelona is a topic of five different analyses. First, Celsa Barcelona's sustainability performance of total energy use will be analysed by measuring activity with total production of metal products (Table 28). Then similar analysis is carried out for energy consumed in the production of four different metal product categories (Tables 29-32), for which the company has provided data in their publicly available reporting.

Table 28 shows results from the analysis of total energy use. Total energy use has first decreased in the studied period, mainly because of decreasing production of metal products in the incremental periods 2010-2011, 2011-2012 and 2012-2013. Since then production has slightly increased energy use. In cumulative terms, energy used has been below the 2010 level during the whole period 2010-2015, so Celsa Barcelona's energy performance has been sustainable. The only exceptions are incremental periods 2013-2014 and 2014-2015.

The sustainable performance of Celsa Barcelona's total energy consumption falls in cases B3 and B6. In case B3, both effects decrease energy use, and SG and SI are negative. Negative SG in case B3 tells that the observed (decreased) activity could increase by a percentage shown by SG, calculated from the observed activity change. Negative SI in case B3 tells that intensity effect could increase energy use with an amount of the SI coefficient multiplied by the observed increase. In case B6, intensity effect increases energy use and activity effect decreases it so much that the sum is negative and energy use decreases. Positive SG in case B6 tells that the decrease in activity could be smaller without threatening sustainability. Positive SI in case B6 tells that the intensity effect could even more increase energy use without threatening sustainability.

Table 28. Sustainability performance indicators SG and SI for Celsa Barcelona's energy consumption, incremental and cumulative analysis, 2010-2015. V = EN = total energy use (gas and electricity), X = PROD = total production.

ASA EN	2010-11	2011-12	2012-13	2013-14	2014-15	2010-11	2010-12	2010-13	2010-14	2010-15
EN/PROD	-0.97	2.02	-1.61	1.74	-0.64	-0.97	1.07	-0.47	1.16	0.57
PROD	-1.65	-9.86	-0.27	-1.25	3.25	-1.65	-11.32	-11.47	-12.67	-9.77
Total (ΔEN)	-2.62	-7.84	-1.88	0.50	2.61	-2.62	-10.25	-11.94	-11.50	-9.19
SG percentage	-58	21	-607	140	20	-58	9	-4	9	6
SI coefficient	-1.76	5.29	-0.17	0.71	4.94	-1.76	11.80	-27.61	12.29	18.73
Case	B3	B6	B3	B5	B1	B3	B6	B3	B6	B6

Tables 29-32 show the results of Celsa Barcelona's energy performance in the production of steel billets (Table 29), wires and rods (Table 30), structural profiles (Table 31) and steel plates (Table 32). The cumulative analysis shows that the energy performance of producing steel billets, structural profiles and steel plates has fulfilled the sustainability criterion, but instead of significantly decreasing intensity, this has happened mostly by decreasing production. Intensity effect has played a minor role especially in production of steel plates and steel billets (Tables 32 and 29). SG values are in general low with these product groups. Intensity effect contributes more significantly in the energy use of production of wires and rods and structural profiles, but the effect often increases energy consumption (Tables 30 and 31).

Table 29. Sustainability performance indicators SG and SI for Celsa Barcelona's energy consumption, incremental and cumulative analysis, 2010-2015. V = EN = energy use for steel billets (gas and electricity), X = PROD = production of steel billets.

ASA EN	2010-11	2011-12	2012-13	2013-14	2014-15	2010-11	2010-12	2010-13	2010-14	2010-15
EN/PROD	-0.37	0.62	-0.42	-1.43	1.29	-0.37	0.26	-0.14	-1.51	-0.32
PROD	-1.99	-7.79	1.27	-1.56	3.38	-1.99	-9.62	-8.44	-9.81	-6.85
Total (ΔEN)	-2.36	-7.17	0.85	-2.99	4.67	-2.36	-9.36	-8.59	-11.32	-7.17
SG percentage	-18	8	33	-91	-38	-18	3	-2	-15	-5
SI coefficient	-5.56	13.62	3.01	-1.13	-2.51	-5.56	41.55	-64.26	-7.34	-22.70
Case	B3	B6	B1	B3	B4	B3	B6	B3	B3	B3

Table 30. Sustainability performance indicators SG and SI for Celsa Barcelona's energy consumption, incremental and cumulative analysis, 2010-2015. V = EN = energy use for wires and rods (gas and electricity), X = PROD = production of wires and rods.

ASA EN	2010-11	2011-12	2012-13	2013-14	2014-15	2010-11	2010-12	2010-13	2010-14	2010-15
EN/PROD	1.77	-1.79	-2.94	6.95	-0.74	1.77	-0.10	-2.93	3.70	3.04
PROD	-1.08	-6.06	4.31	0.79	5.22	-1.08	-7.12	-3.02	-2.37	2.84
Total (ΔEN)	0.69	-7.85	1.37	7.74	4.48	0.69	-7.22	-5.95	1.34	5.87
SG percentage	164	-29	68	-879	14	164	-1	-97	156	-107
SI coefficient	0.61	-3.68	1.45	-0.11	6.72	0.61	-79.50	-1.10	0.63	-0.88
Case	B5	B3	B1	B4	B1	B5	B3	B3	B5	B4

Table 31. Sustainability performance indicators SG and SI for Celsa Barcelona's energy consumption, incremental and cumulative analysis, 2010-2015. V = EN = energy use for structural profiles (gas and electricity), X = PROD = production of structural profiles

ASA EN	2010-11	2011-12	2012-13	2013-14	2014-15	2010-11	2010-12	2010-13	2010-14	2010-15
EN/PROD	0.07	5.47	-0.40	0.24	-1.50	0.07	5.53	5.14	5.33	3.96
PROD	-0.40	-8.19	0.78	-2.40	5.34	-0.40	-8.57	-7.82	-10.11	-5.09
Total (ΔEN)	-0.32	-2.73	0.37	-2.16	3.83	-0.32	-3.04	-2.68	-4.78	-1.13
SG percentage	19	67	52	10	28	19	65	66	53	78
SI coefficient	5.35	1.54	1.91	10.09	3.42	5.35	1.60	1.56	1.99	1.30
Case	B6	B1	B1	B6	B1	B6	B6	B6	B6	B6

Table 32. Sustainability performance indicators SG and SI for Celsa Barcelona's energy consumption, incremental and cumulative analysis, 2010-2015. V = EN = energy use for steel plates, X = PROD = production of steel plates.

ASA EN	2010-11	2011-12	2012-13	2013-14	2014-15	2010-11	2010-12	2010-13	2010-14	2010-15
EN/PROD	-4.03	5.33	-1.91	0.99	1.15	-4.03	1.35	-0.44	0.40	1.38
PROD	-4.46	-19.44	-9.73	-2.00	-5.66	-4.46	-22.75	-30.11	-31.65	-35.72
Total (ΔEN)	-8.49	-14.10	-11.64	-1.02	-4.51	-8.49	-21.40	-30.54	-31.25	-34.35
SG percentage	-90	27	-20	49	20	-90	6	-1	1	4
SI coefficient	-1.21	4.24	-5.77	2.05	5.13	-1.21	21.41	-99.47	114.49	39.56
Case	B3	B6	B3	B6	B6	B3	B6	B3	B6	B6

Analysis of use of raw materials

Celsa Barcelona uses scrap and steel alloys as the major raw materials in the production processes. The sustainability performance analysis of material use is carried out for the total use of scrap and steel alloys by using total production as a variable describing the activity (Table 33). The use of scrap and steel alloys has decreased during the studied period, only in 2012-2013 and 2013-2014 the use has slightly increased. Incremental analysis shows that the decrease comes mostly from the activity effect (decreasing production). The intensity effect has decreases use of raw materials in two periods only, in 2010-2011 and 2014-2015. Cumulative analysis shows that raw material use has stayed 8-10 % below the 2010 level since 2011 and the performance falls into the sustainable case B6. Positive SG values are low (8-38 %) which means that the sustainability criterion could have been fulfilled with a much smaller decrease in production. Relatively high positive SI coefficients tell that the increase of raw material consumption caused by the intensity effect could have been 2.84-13.38 times larger than the observed one.

Table 33. Sustainability performance indicators SG and SI for Celsa Barcelona's use of raw materials, incremental and cumulative analysis, 2010-2015. V = RM = use of scrap and steel alloys, X = PROD = total production.

ASA RM	2010-11	2011-12	2012-13	2013-14	2014-15	2010-11	2010-12	2010-13	2010-14	2010-15
RM/PROD	-0.43	1.45	0.63	3.47	-4.28	-0.43	1.02	1.62	4.94	0.80
PROD	-1.66	-9.83	-0.27	-1.26	3.19	-1.66	-11.32	-11.60	-12.92	-9.78
Total (ΔRM)	-2.09	-8.38	0.36	2.22	-1.08	-2.09	-10.30	-9.97	-7.98	-8.98
SG percentage	-26	15	234	276	134	-26	9	14	38	8
SI coefficient	-3.92	7.39	0.43	0.35	0.75	-3.92	12.32	7.95	2.84	13.38
Case	B3	B6	B5	B5	B2	B3	B6	B6	B6	B6

Analysis of environmental impacts

In the following, the environmental performance of Celsa Barcelona is analysed. CO_2 emissions is used as a variable describing environmental impact. Total energy use, use of raw materials (scrap and steel alloys) and total production are used as variables of activity (Tables 34-36, correspondingly). CO_2 emissions have decreased during the studied period. Only in 2014-2015 they have increased.

When activity is measured with total energy use, the activity effect has decreased emissions in all incremental periods, except the most recent one (Table 34). Intensity effect has also decreased emissions, but in 2013-2014 and 2014-2015 the intensity effect has been an increasing one. Performance in all studied periods except two most recent incremental periods falls into the sustainable case B3, where both effects have decreased CO_2 emissions. The SG and SI values are negative, so sustainability would not be threatened, if total energy use had increased instead of the observed decrease (SG), or the intensity had increased instead of the observed decrease, and increased emissions with the observed change in total energy use.

Table 34. Sustainability performance indicators SG and SI for Celsa Barcelona's environmental impacts, incremental and cumulative analysis, 2010-2015. V = ES = CO_2 emissions, X = EN = total energy use.

ASA ES	2010-11	2011-12	2012-13	2013-14	2014-15	2010-11	2010-12	2010-13	2010-14	2010-15
ES/EN	-1.63	-1.72	-3.27	-1.01	2.78	-1.63	-3.24	-6.21	-7.11	-4.78
EN	-2.60	-7.77	-1.85	0.49	2.64	-2.60	-10.08	-11.54	-11.07	-8.96
Total (ΔES)	-4.23	-9.49	-5.12	-0.51	5.43	-4.23	-13.32	-17.76	-18.18	-13.74
SG percentage	-63	-22	-177	204	-105	-63	-32	-54	-64	-53
SI coefficient	-1.67	-4.98	-0.59	0.49	-0.90	-1.67	-3.59	-2.26	-1.90	-2.17
Case	B3	B3	B3	B2	B4	B3	B3	B3	B3	B3

When activity is measured with use of raw material (scrap and steel alloys), the activity effect has decreased emissions in incremental periods 2010-2011. 2011-2012 and 2014-2015 (Table 35). Intensity effect has decreased emissions in all incremental periods except the most recent one, 2014-2015. Performance in almost all periods is sustainable, the most common case is again B3. The SG and SI values are negative, so sustainability would not be threatened, if raw material use had increased instead of the observed decrease, or CO_2 intensity of material use had increased instead of the observed decrease.

Table 35. Sustainability performance indicators SG and SI for Celsa Barcelona's environmental impacts, incremental and cumulative analysis, 2010-2015. V = ES = CO_2 emissions, X = RM = use of scrap and steel alloys.

ASA ES	2010-11	2011-12	2012-13	2013-14	2014-15	2010-11	2010-12	2010-13	2010-14	2010-15
ES/RM	-2.16	-1.16	-5.47	-2.70	6.55	-2.16	-3.20	-8.22	-10.64	-5.00
RM	-2.07	-8.33	0.35	2.19	-1.12	-2.07	-10.12	-9.54	-7.54	-8.74
Total (ΔES)	-4.23	-9.49	-5.12	-0.51	5.43	-4.23	-13.32	-17.76	-18.18	-13.74
SG percentage	-104	-14	1568	124	585	-104	-32	-86	-141	-57
SI coefficient	-1.00	-7.91	0.07	0.81	0.16	-1.00	-3.65	-1.41	-0.87	-2.03
Case	B3	B3	B2	B2	B5	B3	B3	B3	B3	B3

When activity is measured with total production (all metal products), the activity effect has decreased CO_2 emissions in all incremental periods except the most recent one (Table 36). Intensity effect has decreased emissions in 2010-2011 and 2012-2013, in other incremental periods the intensity effect has been slightly an increasing one. In the cumulative analysis, intensity effect has decreased CO_2 emissions in all periods. Performance has been sustainable in all studied periods except the most recent incremental period. Again, the most common case is B3, where SG and SI values are negative.

Table 36. Sustainability performance indicators SG and SI for Celsa Barcelona's environmental impacts, incremental and cumulative analysis, 2010-2015. V = ES = CO_2 emissions, X = PROD = total production.

ASA ES	2010-11	2011-12	2012-13	2013-14	2014-15	2010-11	2010-12	2010-13	2010-14	2010-15
ES/PROD	-2.59	0.28	-4.86	0.72	2.13	-2.59	-2.19	-6.67	-6.00	-4.22
PROD	-1.64	-9.77	-0.26	-1.24	3.30	-1.64	-11.13	-11.09	-12.19	-9.52
Total (ΔES)	-4.23	-9.49	-5.12	-0.51	5.43	-4.23	-13.32	-17.76	-18.18	-13.74
SG percentage	-158	3	-1861	59	-65	-158	-20	-60	-49	-44
SI coefficient	-0.66	38.48	-0.06	1.72	-1.47	-0.66	-5.86	-2.02	-2.48	-2.62
Case	B3	B6	B3	B6	B4	B3	B3	B3	B3	B3

CNPC

The fifth case company is Chinese National Petroleum Company (CNPC). For energy companies, raw material consumption (primary energy), environmental impacts, and production of energy carriers are significant variables to be taken into consideration when the sustainability performance is analysed. CNCP's publicly available data includes these variables for the aggregated consortium level. Usable data on environmental impacts is almost totally absent in the CNCP reports; time series data is available on the amount of oil pollutants in wastewater only. Data on raw materials includes crude oil production in the Chinese territory (domestic production) and total crude oil production (domestic and overseas production). Here separate analyses have been made with both, although total production is perhaps a better choice. Data on production includes the total amount of refined oil products from CNCP's oil refineries. No product-specific time series data is available.

For the decomposition analysis and calculation of the sustainability performance indicators SG and SI, the following five choices were made:

- V = total crude oil production (RM), X = total amount of refined oil products (PROD); Table 37
- V = domestic crude oil production (RM), X = total amount of refined oil products (PROD); Table 38
- V = oil pollutants in wastewater (ES), X = total crude oil production (RM); Table 39
- V = oil pollutants in wastewater (ES), X = domestic crude oil production (RM); Table 40
- V = oil pollutants in wastewater (ES), X = total amount of refined products (PROD); Table 41

Decomposition analysis and calculation of the sustainability performance indicators SG and SI were carried out for annual changes between the years 2010-2014 (moving base year) and for cumulative changes during the same period (fixed base year 2010). Tables 37-41 show results from these decompositions. In each table, the first row includes the intensity effect, second row shows the activity effect and third row is the sum of the effects, i.e. the change of the decomposed variable V. The intensity and activity effect and the sum are presented as percentage (%) from the reference year's absolute value of the decomposed variable V. The reference value in incremental analysis (yellow background) is the previous year's value and in the cumulative analysis (pink background) the fixed value of the year 2010). Fourth row shows the SG value (in percentage from the observed activity change ΔX), and fifth row shows the coefficient value of SI. The sustainable intensity can be calculated by multiplying the calculated intensity effect (first row) with the calculated coefficient value. The last row shows in which case (B1-B6) the incremental or cumulative performance belongs to. As noted above, cases B2, B3 and B6 are sustainable and cases B1, B4 and B5 are unsustainable.

Analysis of use of raw materials (primary energy)

Raw material use in CNPC is measured with all crude oil production (Table 37) and domestic crude oil production (Table 38). Activity is measured in both tables with the amount of refined products. The results are very similar, as expected. An interesting result is that the intensity effect has decreased crude oil production in both analyses in all studied periods except 2012-2013. Because the amount of refined products has increased annually, crude oil production has increased and the performance is unsustainable, case B1 dominates the observations. The sustainable part of crude oil production (SG) remains quite low, and the SI values tell that the intensity decrease should be larger (Tables 37 and 38).

Table 37. Sustainability performance indicators SG and SI for CNPC's use of raw materials (primary energy), incremental and cumulative analysis, 2010-2014. V = RM = all oil production, X = PROD = refined products.

ASA RM	2010-11	2011-12	2012-13	2013-14	2014-15	2010-11	2010-12	2010-13	2010-14	2010-15
RM/PROD	-2.11	-1.86	3.63	-1.27		-2.11	-4.05	-0.39	-1.75	
PROD	7.65	3.61	1.59	4.00		7.65	11.43	13.38	17.82	
Total (ΔRM)	5.54	1.75	5.22	2.73		5.54	7.38	12.99	16.07	
SG percentage	28	52	-227	32		28	35	3	10	
SI coefficient	3.43	1.91	-0.42	3.06		3.43	2.63	30.38	8.77	
Case	B1	B1	B4	B1		B1	B1	B1	B1	

Table 38. Sustainability performance indicators SG and SI for CNPC's use of raw materials (primary energy), incremental and cumulative analysis, 2010-2014. V = RM = domestic oil production, X = PROD = refined products.

ASA RM	2010-11	2011-12	2012-13	2013-14	2014-15	2010-11	2010-12	2010-13	2010-14	2010-15
PM/PROD	-5.50	-1.03	0.49	-3.01		-5.50	-6.62	-6.19	-9.36	
PROD	7.52	3.63	1.57	3.97		7.52	11.29	13.01	17.19	
Total (ΔEN)	2.02	2.59	2.06	0.95		2.02	4.67	6.82	7.84	
SG percentage	73	28	-31	76		73	59	48	54	
SI coefficient	1.34	3.42	-3.16	1.30		1.34	1.63	1.97	1.70	
Case	B1	B1	B4	B1		B1	B1	B1	B1	

Analysis of environmental impacts

Environmental performance of CNPC is analysed in the following by using oil pollutants in wastewater as variable describing environmental impact. This is the only variable with time series data available in CNPC's publicly available reporting. Activity is measured with three variables: all oil production (Table 39), domestic oil production (Table 40), and refined oil products (Table 41).

Oil pollutants in wastewater have decreased in all studied periods and with all variables describing the activity, i.e. all crude oil production, domestic oil production and the amount of refined oil products (Tables 39-41). Thus, the performance of CNPC is sustainable throughout the whole studied period in both incremental and cumulative analysis and all variable combinations. The performance belongs to case B2, where the intensity effect has decreased the amount of oil pollutants in wastewater more than the activity has increased them. SG values are over 100 % and SI coefficients are always less than 1. Unfortunately, no other environmental time series data was available in the CNPC publicly available reporting.

Table 39. Sustainability performance indicators SG and SI for CNPC's environmental impacts, incremental and cumulative analysis, 2010-2014. V = ES = oil pollutants in wastewater, X = RM = all oil production.

ASA ES	2010-11	2011-12	2012-13	2013-14	2014-15	2010-11	2010-12	2010-13	2010-14	2010-15
ES/RM	-12.53	-11.50	-8.99	-21.19		-12.53	-23.01	-30.90	-47.38	
RM	5.20	1.65	4.99	2.44		5.20	6.56	11.10	12.55	
Total (ΔES)	-7.33	-9.85	-4.00	-18.75		-7.33	-16.45	-19.79	-34.83	
SG percentage	241	697	180	867		241	351	278	378	
SI coefficient	0.45	0.16	0.58	0.14		0.45	0.34	0.45	0.41	
Case	B2	B2	B2	B2		B2	B2	B2	B2	

Table 40. Sustainability performance indicators SG and SI for CNPC's environmental impacts, incremental and cumulative analysis, 2010-2014. V = ES = oil pollutants in wastewater, X = RM = domestic oil production.

ASA ES	2010-11	2011-12	2012-13	2013-14	2014-15	2010-11	2010-12	2010-13	2010-14	2010-15
ES/RM	-9.25	-12.28	-6.00	-19.61		-9.25	-20.65	-25.77	-41.12	
RM	1.93	2.44	2.00	0.86		1.93	4.20	5.97	6.29	
Total (ΔES)	-7.33	-9.85	-4.00	-18.75		-7.33	-16.45	-19.79	-34.83	
SG percentage	480	504	300	2286		480	492	431	654	
SI coefficient	0.22	0.22	0.35	0.05		0.22	0.24	0.29	0.23	
Case	B2	B2	B2	B2		B2	B2	B2	B2	

Table 41. Sustainability performance indicators SG and SI for CNPC's environmental impacts, incremental and cumulative analysis, 2010-2014. V = ES = oil pollutants in wastewater, X = PROD = refined oil products.

ASA ES	2010-11	2011-12	2012-13	2013-14	2014-15	2010-11	2010-12	2010-13	2010-14	2010-15
ES/PROD	-14.51	-13.26	-5.52	-22.33		-14.51	-26.64	-31.23	-48.78	
PROD	7.19	3.41	1.52	3.58		7.19	10.19	11.44	13.95	
Total (ΔES)	-7.33	-9.85	-4.00	-18.75		-7.33	-16.45	-19.79	-34.83	
SG percentage	202	389	363	623		202	262	273	350	
SI coefficient	0.53	0.29	0.29	0.20		0.53	0.46	0.46	0.44	
Case	B2	B2	B2	B2		B2	B2	B2	B2	

Comparative analysis

The analysed companies are very different, so there is no explicit reason to make a detailed comparative analysis of the results achieved. Stora Enso and Celsa Barcelona are industrial companies in different branches, ENEL, RWE and CNPC are large energy companies operating mostly in different countries. Stora Enso as a global forest corporation operates in an energy intensive branch of pulp and paper/cardboard production, Celsa Barcelona is a part of international Celsa Group, produces different metal products from scrap and steel alloys in a local site, and consumes a lot of electricity and gas. ENEL and RWE are international energy companies with own electricity production, and CNPC is one of the World's largest oil producers and refiners. The publicly available data in the reports and other sources is very different, some companies offer data for different products or product groups (ENEL, RWE, Celsa Barcelona), others offer data for the whole company only (Stora Enso, CNPC). The data was collected from the year 2010 onwards, and the most recent year of available data varies between 2014 and 2016. Environmental and material performance has been analysed in all companies. Energy performance is analysed only in industrial companies Stora Enso and Celsa Barcelona by using this term. In energy companies, primary energy is considered as a raw material. It is worth noting here that a same variable may have different roles in different analyses for a same company. This is visible in the introductory part of each analysed company above, where the company-specific analyses and result tables have been listed.

However, some general observations can be made on the basis of the results from analyses carried out above for the five case companies. First, it can be said that decrease in activity characterises many analysed European companies, not depending on the measure of activity (amount of production, amount of raw material used, or amount of energy consumed). This is especially with the two industrial companies, but also with the two energy companies. Tables 42-47 below show how the sustainability performance of the five analysed companies represents the different cases B1-B6 in the incremental and cumulative analyses. The results are grouped also by the analysed variable, i.e. in energy performance (Tables 42 and 43), material performance (Tables 44 and 45), and environmental performance (Tables 46 and 47).

Energy performance was analysed only for the industrial companies Stora Enso and Celsa Barcelona. The most common cases are highlighted with bold in Tables 42 and 43. The energy performance of Stora Enso has been sustainable in 8 out of 12 incremental periods and in 9 out of 12 cumulative periods (Tables 42 and 43; cases B2, B3 and B6). In incremental analyses, the most common cases have been B3 (sustainable) and B5 (unsustainable). In cumulative analysis, the most common case has been B6 (quasi-sustainable), where the decreasing effect of activity is larger than the increasing effect of intensity. In Celsa Barcelona, energy performance has been sustainable in 14 out of 25 incremental analyses and in 12 out of 25 cumulative analyses (Tables 42 and 43; cases B2, B3 and B6). The most common cases in incremental analyses have been B1 (unsustainable), B3 (sustainable) and B6 (quasi-sustainable). In cumulative analyses, the most common case for Celsa Barcelona has been B6 (quasi-sustainable).

Table 42. Number of incremental energy consumption analyses in the case companies by performance case B1-B6.

	Energy performance, number of incremental analyses					
Case	**Stora Enso**	**ENEL**	**RWE**	**Celsa Barcelona**	**CNPC**	**Total**
B1	-	-	-	**7**	-	7
B2	1	-	-	-	-	1
B3	**4**	-	-	**7**	-	**11**
B4	-	-	-	2	-	2
B5	**4**	-	-	2	-	6
B6	3	-	-	**7**	-	10
Total	12	-	-	25	-	37

Table 43. Number of cumulative energy consumption analyses in the case companies by performance case B1-B6.

	Energy performance, number of cumulative analyses					
Case	**Stora Enso**	**ENEL**	**RWE**	**Celsa Barcelona**	**CNPC**	**Total**
B1	-	-	-	-	-	-
B2	-	-	-	-	-	-
B3	3	-	-	10	-	13
B4	-	-	-	1	-	1
B5	-	-	-	2	-	2
B6	**9**	-	-	**12**	-	**21**
Total	12	-	-	25	-	37

Material performance was analysed for all companies. In energy companies ENEL, RWE and CNPC the raw material is primary energy sources. The most common cases are highlighted with bold in Tables

44 and 45. The material performance of ENEL has been sustainable in 18 out of 33 incremental periods and in 14 out of 33 cumulative periods (Tables 44 and 45; cases B2, B3 and B6). In incremental analyses, the most common case has been B4 (unsustainable) and in cumulative analysis B1 (unsustainable). In RWE, material performance has been sustainable in 13 out of 24 incremental analyses and in 8 out of 24 cumulative analyses (Tables 44 and 45; cases B2, B3 and B6). The most common cases in incremental analyses have been B2 (sustainable, B4 (unsustainable) and B6 (quasi-sustainable). In cumulative analyses of RWE, the most common case has been B5 (unsustainable), where intensity effect increases material (primary energy) use more than the activity effect decreases it. In CNCP, material performance was unsustainable in all eight analyses in both incremental and cumulative periods, all of them fell either in case B1 where activity effect increases material use more than the intensity effect decreases it, or B4 where both effects increase material use (Tables 44 and 45).

In Stora Enso, performance in wood use has been sustainable in 5 out of 6 incremental periods and in all six cumulative periods (Tables 44 and 45). The most common case has been B6 (quasi-sustainable), where activity effect decreases wood use more than intensity effect increases it. In Celsa Barcelona, 3 out of 5 incremental and all five cumulative analyses were sustainable (tables 44 and 45). In incremental periods, the most common case was, however, B5 (unsustainable) and in cumulative periods, the most common case was B6 (quasi-sustainable).

Table 44. Number of incremental analyses of material consumption in the case companies by performance case B1-B6.

	Material performance, number of incremental analyses					
Case	**Stora Enso**	**ENEL**	**RWE**	**Celsa Barcelona**	**CNPC**	**Total**
B1	-	4	3	-	**6**	13
B2	-	8	**5**	1	-	14
B3	1	6	3	1	-	11
B4	-	**9**	**5**	-	2	**16**
B5	1	2	3	**2**	-	8
B6	**4**	4	**5**	1	-	14
Total	6	33	24	5	8	76

Table 45. Number of cumulative analyses of material consumption in the case companies by performance case B1-B6.

	Material performance, number of cumulative analyses					
Case	**Stora Enso**	**ENEL**	**RWE**	**Celsa Barcelona**	**CNPC**	**Total**
B1	-	**9**	4	-	**8**	**21**
B2	-	4	2	-	-	6
B3	-	3	4	1	-	8
B4	-	3	3	-	-	6
B5	-	8	**9**	-	-	17
B6	**6**	6	2	**4**	-	18
Total	6	33	24	5	8	76

Environmental performance was analysed in all case companies. In Stora Enso, environmental performance was sustainable in 12 out of 18 incremental analyses and in all 18 cumulative analyses (Tables 46 and 47). The most common case was B3 (sustainable, where both effect decrease environmental impact measured with CO_2 emissions) in 9 incremental and all 18 cumulative periods. In Celsa Barcelona, environmental performance was sustainable in 4 out of 5 incremental analyses and in all five cumulative analyses (Tables 46 and 47). The most common case in both was B3.

In ENEL, environmental performance was sustainable in 4 out of 10 incremental and cumulative analyses (Tables 46 and 47). The most common cases were B4 (unsustainable) in incremental and B1 (unsustainable) in cumulative periods. In RWE, performance was sustainable in 28 out of 46 incremental analyses and in 26 out of 46 cumulative analyses (Tables 46 and 47). The most common vases were B3 (sustainable) and B4 (unsustainable) in incremental and cumulative periods, correspondingly. In CNPC, environmental performance was sustainable in all incremental and cumulative analyses, and all analyses fell in case B2 where intensity effect decreases environmental impact more than the activity effect increases it (Tables 46 and 47).

Table 46. Number of incremental analyses of environmental impacts in the case companies by performance case B1-B6.

	Environmental performance, number of incremental analyses					
Case	**Stora Enso**	**ENEL**	**RWE**	**Celsa Barcelona**	**CNPC**	**Total**
B1	1	2	7	-	-	10
B2	1	1	6	1	**8**	17
B3	**9**	2	**16**	**3**	-	**30**
B4	1	**4**	7	1	-	13
B5	4	-	4	-	-	8
B6	2	1	6	-	-	9
Total	18	10	46	5	8	87

Table 47. Number of cumulative analyses of environmental impacts in the case companies by performance case B1-B6.

	Environmental performance, number of cumulative analyses					
Case	**Stora Enso**	**ENEL**	**RWE**	**Celsa Barcelona**	**CNPC**	**Total**
B1	-	**3**	1	-	-	4
B2	-	2	5	-	**8**	15
B3	**18**	-	10	**5**	-	**33**
B4	-	2	**16**	-	-	18
B5	-	1	3	-	-	4
B6	-	2	11	-	-	13
Total	18	10	46	5	8	87

Conclusions

In this deliverable, two new sustainability performance indicators have been presented, end their values have been calculated for five case companies using the company-level data collected in EUFORIE deliverable D6.1 (Vehmas & Ameziane 2017). The indicators can be applied at all levels in all economic activities using energy and materials and causing environmental impacts, so they fulfill the request of flexibility highlighted by companies (in the context of energy efficiency; see Vehmas et al 2017). In addition to the applicability at all levels an all time periods, the indicators allow different data choices − only two variables with an assumed causal relationship are required. The indicators describe the performance of companies and other economic systems in energy use, material used, and environmental impacts in the light of economic activity and energy, material, and environmental intensity of the activity. The idea is to see the contributions of activity and intensity effects to a change in energy consumption, raw material consumption, or an environmental impact. The activity and intensity effect can be calculated with any preferred decomposition method, and the sustainability performance indicators, sustainable growth (SG)and sustainable intensity (SI), are defined by utilizing the relationship between the intensity and activity effect.

In addition to the opportunities mentioned above, the new indicators have also their challenges. One analysis uses only two variables, so the sustainability performance of a large company requires several analyses. Because the variables included in the analyses can either increase or decrease over time, there are six different cases (B1-B6 above), half of them are sustainable and the other half are unsustainable. Because cases B1 and B6, B2 and B5, and B3 and B4 can get similar values for the new indicators, the indicators are not stand-alone ones. This means that conclusions cannot be drawn from the pure indicator values alone. Identification of the case is of great importance. Despite of these challenges, interpretation of the indicator values in each case is clear from the point of view of the sustainability criterion, which is relative to the reference year's situation. Thus, the usability of the new indicators should not be a problem. Annual changes of the relevant variables can be positive or negative, so the annual values of the sustainable performance indicators may also vary a lot. Thus, there is a reason to prefer longer time periods, so cumulative analysis, i.e. calculating the indicator values in relation to a fixed base year is an attractive option.

The following conclusions about the data challenge taken from deliverable D6.1 (Vehmas & Ameziane 2017) will be repeated here, because they are relevant not only for the ASA but for all other decomposition analyses too, and furthermore, they may be considerable also when the content of the new sustainability performance indicators presented here are applied in practice:

"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 in the master equations presented above. 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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