Sectoral Intensity Target Approach to Corporate Greenhouse-gas Emission Targets (SITA)

Aligning corporate climate action with the 2 °C target

MSc Thesis
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Context

Master program Energy Science

The master program in Energy Science studies the sustainability of the production, treatment and use of energy and materials. The program gives a detailed insight into the development of energy and material use over time; into current and future energy technologies (including renewable energy) such as solar cells, biomass and wind; bio-based materials; and energy and climate policies. Graduates are able to contribute to the transitions towards sustainable energy and material systems by doing applied research, consultancy work or giving policy advice.

Annotation Sustainable Entrepreneurship & Innovation

Students enrolled in the Energy Science master program can qualify themselves for the annotation Sustainable Entrepreneurship & Innovation next to their master's degree and receive an additional certificate. A requirement to qualify for this annotation is that the subject of the master thesis is related to sustainable entrepreneurship & innovation.

This thesis qualifies for the annotation because the SITA target-setting methodology can be regarded as an innovation. Furthermore, implementing this methodology promotes the implementation of sustainable production processes and/or services.

Climate-KIC master label

Climate-KIC is one of three Knowledge and Innovation Communities (KICs) created in 2010 by the European Institute of Innovation and Technology (EIT). The EIT is an EU body whose mission is to create sustainable growth. Climate-KIC supports this mission by addressing climate change mitigation and adaptation. Climate-KIC integrates education, entrepreneurship and innovation resulting in connected, creative transformation of knowledge and ideas into economically viable products or services that help to mitigate climate change.

The Climate-KIC Master Programme adds extra value to selected master degree programmes at their partner universities. After successful completion, students receive a Climate-KIC certificate in addition to their regular degree. As part of this master programme, students have to write their master thesis on a topic related to climate change and entrepreneurship. This thesis qualifies for the Climate-KIC master label because the SITA methodology promotes the setting of sustainable emissions targets by large companies, resulting in climate change mitigation.

Summary

Climate change poses one of the greatest threats facing the planet today. As the main cause of climate change is the anthropogenic emission of greenhouse-gases, the Intergovernmental Panel on Climate Change has repeatedly stressed the importance of acting to reduce those emissions. However, governments have not yet adequately implemented policies that result in limiting global warming to 2 °C; an internationally accepted target that would avert catastrophic climate change. Because current policies are not reducing enough emissions, more and more companies engage in voluntary climate action. To promote this climate action in their organizations, they set greenhouse-gas emission targets.

Most companies set their emission targets in an arbitrary way, without them knowing whether their efforts are sufficient to be in line with the 2 °C target. Methods have been developed that align the emission targets with the 2 °C target, but these methods have significant limitations. A large share of these limitations is due to the high level of aggregation; one target is applied to all companies, not accounting for sectoral differences.

This thesis proposes the sectoral intensity target approach (SITA). By using the International Energy Agency's 2 degree scenario, sector specific pathways are constructed for 13 sectors that result in meeting the 2 °C target. Next, the annual CO_2 budget for the sectors is allocated to companies in those sectors based on their activity (e.g. production). In this way, sector specific CO_2 emission intensity pathways are constructed that represent the fair share of CO_2 emissions per unit of activity.

In order to be in line with the 2 °C target, companies must converge their emission intensity towards the sectoral pathway. In 2050, the company's intensity must be equal to the sectoral intensity target. SITA can be used by companies to set sustainable GHG emission targets. Furthermore, because SITA uses publicly available data, NGOs can use the SITA target as a benchmark to evaluate corporate CO_2 emission targets. NGOs are planning to actively monitor the emission targets of large companies and publish their performance in order to promote voluntary climate action.

Contents

1. Introduction

Climate change poses one of the greatest environmental, social and economic threats facing the planet. In its contribution to the 2014 Fifth Assessment Report, which reviews all major empirical findings regarding climate change, Working Group I of the Intergovernmental Panel on Climate Change (IPCC) states that: *"Warming of the climate is unequivocal"*(IPCC, 2013, p. 4). Furthermore, Working Group I states that the largest part of this warming is caused by the increase in the concentration of greenhouse-gases (GHGs) such as carbon dioxide (CO_2) and methane (CH_4) in the atmosphere (IPCC, 2013). According to the scientific community, the world is getting warmer and the emission of GHGs is the main cause. Global warming has a wide range of negative impacts including decreased crop yields, rising sea level and increase of weather extremes (IPCC, 2013). In order to reduce climate change damages, risk and impacts, reducing the amount of emitted GHGs is crucial (Meinshausen, Meinshausen, Hare, et al., 2009).

1.1. The 2 °C target

Before the IPCC released its 2013 report, it was already clear to the Council of the European Union that climate change is posing a social, environmental and economic threat. In 2005 the European Council agreed with the ultimate objective of keeping the global mean surface temperature increase under 2 °C above pre-industrial levels set by the United Nations Framework Convention on Climate Change (UNFCCC) (Council of the European Union, 2005). This target would prevent dangerous anthropogenic interference with the climate system. In 2009, representatives of 144 countries signed the Copenhagen Accord, thereby agreeing with the "below 2 °C global warming" target.

Translating this 2 °C target into GHG emissions targets is difficult due to uncertainties about the climate system dynamics (Meinshausen et al., 2009). However, several authors and organizations have used integrated assessment models (IAMs) to develop scenarios that most likely result in achieving the 2 °C target (Meinshausen et al., 2009; UNEP, 2011; van Vuuren, Stehfest, den Elzen, et al., 2011). These scenarios provide global emission reductions pathways that are required to stay below 2 °C global warming.

1.2. The GHG emissions gap

Although several countries have made pledges to reduce their emissions, there is still a large gap between the emission pathways resulting from these pledges and the emission pathways towards the 2 °C target (Figure 1). The United Nations Environment Programme (UNEP) first reported about this emissions gap in 2010 (UNEP, 2010). In the following years, UNEP released updated emissions gap reports, describing how the gap widens and possible means to bridge the gap (UNEP, 2011, 2012, 2013). Other authors also provided possible means to bridge the emissions gap (Blok, Höhne, van der Leun, et al., 2012; den Elzen, Hof, & Roelfsema, 2011). In all these scenarios, there is a significant role for large companies through voluntary climate action. This large role can be explained by the size of large companies. Some of the world's largest companies are larger than countries, when looking at contribution to global gross domestic product (GDP) (Grauwe & Camerman, 2003). Figure 2 illustrates this by looking at the GDP and value added (VA; contribution to GDP) of a set of illustrative countries and companies (adapted from Grauwe & Camerman (2003)). The sheer size of companies enables them to have a significant impact by changing their practices.

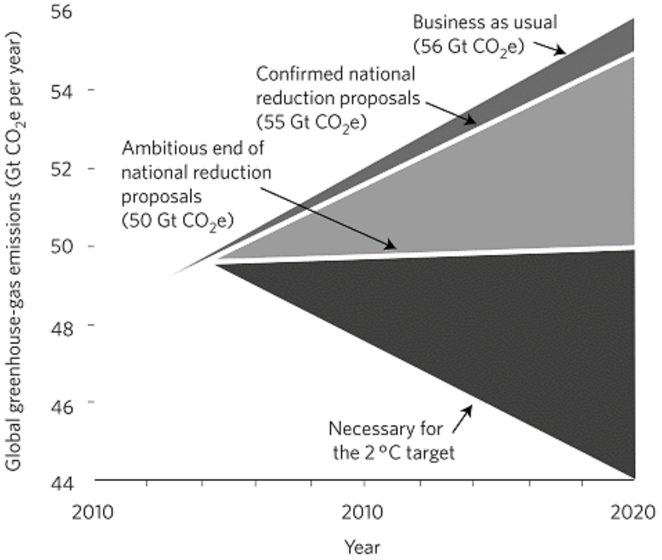

Figure 1: The GHG emissions gap (Blok et al., 2012).

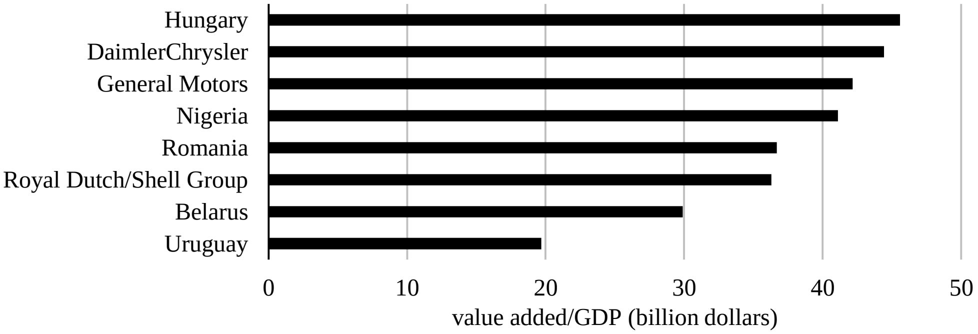

Figure 2: VA and gross domestic product of illustrative companies and countries.

1.3. Corporate climate action

Most large companies have already set GHG emission targets in order to become more sustainable. CDP (formerly known as the Carbon Disclosure Project) performed a study on emission targets of large companies and found that 73 of Global 100 companies have some form of reduction target (Carbon Disclosure Project, 2008). Although most (62%) of these targets are defined in terms of CO_2-equivalent[1] (CO_2eq), there are several other types of targets being used: energy efficiency targets, energy consumption targets, emission targets targeting other GHGs, etc. (Carbon Disclosure Project, 2008). Most of the targets are based on absolute emissions and focus on the short term (e.g. total company annual GHG emissions -10% in 2015). They are often arbitrarily determined and the targets of the Global 100 are not sufficient to stay within 2 °C global warming (Carbon Disclosure Project, 2008; Kolk & Pinkse, 2004). Furthermore, because of the wide range of different targets, it is hard to determine whether companies are doing their fair share of GHG emission reductions.

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[1] The mass of non-CO_2 GHGs are represented by a mass of CO_2 with the same global warming potential (GWP). Because different gases have different lifetimes in the atmosphere, a commonly used (but rather arbitrary) time horizon of 100 years is used. This time horizon is also used in this thesis.

There are however companies that make an extra effort in their target-setting practices. Ford, for example, has determined targets based on a pathway to a stabilized CO_2 concentration of 450 ppm. However, Ford is not transparent in its specific methods and focuses only on the emissions of its products in the use phase, and not those arising from automobile manufacturing (Ford, 2013). Other companies are transparent in their method, like BT with their climate stabilization intensity (CSI) method (Tuppen, 2009). This is a method that is published clearly and transparently, but BT's method uses VA as a measure of corporate activity, and therefore does not account for differences between industries or differences in reduction potential. Setting targets on a GHG emission per $ VA results in unfair targets. For example, an expensive (luxury brand) sweater would seem less carbon intensive than a cheap sweater although the emissions per sweater are the same. Furthermore, the corporate target-setting methods only cover direct emissions; they do not incentivize reducing indirect emissions such as the GHGs that are emitted during generation of electricity.

Companies have no target-setting method that enables them to determine their fair share of climate action towards the 2 °C target. However, the amount of corporate interest for the topic suggests that there is a need for such a methodology.

1.4. Scientific approaches to GHG emission target-setting

In addition to the corporate action, there are also scientific initiatives that address the issue of science-based emissions target-setting: VA-based and context-based metrics. A Norwegian climate strategist developed a methodology that uses GHG emissions per VA (GEVA) as an intensity indicator (Randers, 2012). However, because of the use of a monetary intensity indicator, the differences between industries and their reduction potential are overlooked. This results in emission targets that are not technically or economically feasible for companies.

The other method is the context-based metric, which was recently developed by Climate Counts and the Center for Sustainable Organizations (CSO) (Climate Counts & Center for Sustainable Organizations, 2013). This metric tries to assess whether a company is on a sustainable path towards a 2 °C target. This metric allocates future emissions based on their base year emissions. This is a disadvantage for companies that already took carbon reduction measures before the base year, while being an advantage for companies that only recently started working on their carbon footprint.

Based on these two methods can be concluded that the currently available scientific target-setting approaches are not adequately setting fair and feasible GHG emission targets.

1.5. A sectoral approach

Existing methodologies have significant shortcomings. Most methods use VA as an indicator of activity. By doing that, the amount of data needed is reduced, but such a monetary indicator does not only reflect changes in activities, but is also affected by changes in other factors like costs and product price (Farla, 2000). This thesis aims to develop a method that uses physical indicators that are more linked to actual company activity. Due to differences among sectors in product and reduction potential, no single physical indicator can be used for all companies. Therefore, a sectoral approach is used that allows to set fair[2] and

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[2] There is no clear consensus on what is fair in the context of climate change. For more on this, see Garvey (2009) or Baer (2002).

feasible targets for each sector. Although a sectoral approach requires more data and a more complicated calculation, this avoids for example that emission targets for electric utilities (which typically show high emissions and high reduction potential) are set in the same way as the targets for aluminium manufacturers (which typically show high emissions, but low reduction potential). For more on aggregation, see Background Box 1.

Considering the corporate interest in the setting of science-based targets, the development of a methodological guidance that enables companies to determine their fair share of emission reductions could result in companies adjusting their emission targets in order to be in line with the 2 °C scenario. Also, with such a methodological guidance, NGOs can objectively look at company GHG emissions to evaluate whether their climate targets are sufficiently ambitious for the 2 °C target. A list of well-performing and badly-performing companies can be published to further incentivize companies to take voluntary climate action.

Background Box 1: Aggregation in the context of emission intensity

The most important difference between the existing emission target-setting methodologies and the methodological guidance proposed in this thesis, is the level of aggregation. Because emission intensity differs even among a company's products (even a seemingly homogeneous industry, like aluminium has different products with different emission intensities) it would be best to have an emission target for every single product. However, that would be very difficult for two reasons: first, estimating product-specific long-term targets requires making a lot of assumptions, resulting in very specific but unrealistic targets; second, companies usually do not have the required detailed emission data and therefore they are not able to assess whether they are meeting such a product-specific target.

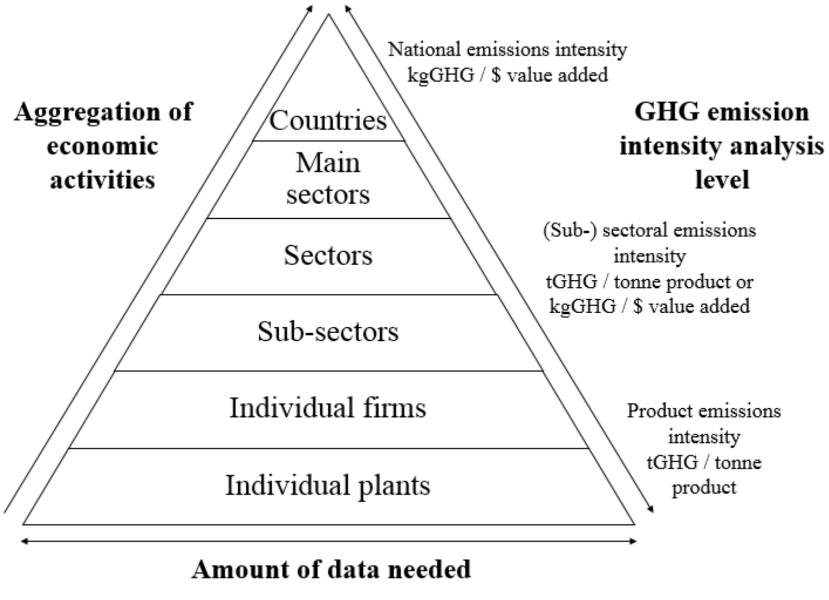

Figure 3: The emission intensity indicator pyramid.

Figure 3 shows the emission intensity indicator pyramid (adapted from Eggink, (2013); Farla, (2000); and Phylipsen, Blok, & Worrell, (1998)). Although theoretically, a non-aggregated target would be best, in practice this is not feasible because of data and time constraints. However, stepping down one level of aggregation (as this thesis proposes) can significantly improve existing methodologies considering that most existing emission target-setting methodologies use a high level of aggregation.

1.6. Research questions

Using GHG emissions that are in line with the 2 °C global warming target as the definition of sustainable GHG emissions, the following research question is formulated:

To what extent can a sectoral approach improve current methodologies that set sustainable corporate GHG emission targets?

In order to answer this research question, the following sub questions are formulated:

- What should a sectoral GHG emission target-setting methodology look like?
- Which corporate GHG emission target-setting methods currently exist and what are their differences?
- When is the proposed sectoral approach a significant improvement of the current approaches?
- In what way can a sectoral approach improve existing methods?
- How does the chosen approach impact the GHG emissions targets?

The next chapter describes the methods used and the conceptual methodology. In chapter 3, the existing methodologies and current practices are reviewed and compared to the conceptual methodology. In chapter 4, the conceptual methodology is complemented with the required data. The proposed sectoral approach is tested on case studies (chapter 5) and the impact of the methodology is assessed (chapter 6). The sensitivity of the proposed methodology is analysed in chapter 7, overall results are discussed in chapter 8 and the conclusions are drawn in chapter 9.

2. Methodology

This chapter describes what a sectoral approach to corporate GHG emissions target-setting entails. First, section 2.1 defines the aim of the target-setting methodology and translates it into goals and methodology requirements. Second, the conceptual methodology is described in section 2.2. Sections 2.3 to 2.5 describe what methods are used for the literature review of other methodologies, the case studies, and the sensitivity analysis.

2.1. Aim, goals and requirements

The aim of a GHG emission target-setting methodology is to promote climate change mitigation. Goals are set that ensure progress towards this aim. The first goal is that implementation of the methodology results in a significant environmental impact. In this case, that means GHG abatement, resulting in less global warming. The next goal is that the methodology is easy to use. This is to decrease barriers resulting from transaction costs (Williamson, 1981) and to increase the likeliness of companies implementing the GHG emissions targets resulting from the methodology. Finally, third parties need to be able to assess whether a company's GHG emissions target is in line with the 2 °C target. Therefore, the target resulting from the methodology must be verifiable.

2.1.1. Environmental impact

The potential GHG abatement resulting from the target-setting methodology is high if the methodology meets the following four requirements. First, the methodology should target large companies, because they have the resources to keep track of their GHG emissions and they account for most of global corporate GHG emissions (Heede, 2013). Second, all the energy-intensive sectors should be covered by the methodology, because they represent most of corporate GHG emissions (IEA, 2012a). Third, direct and indirect emissions of all 6 Kyoto GHGs as well as those resulting from activities in the supply chain should be covered by the methodology (GHG protocol scopes 1, 2, and 3. See Box 2). Fourth, in order to stabilize CO_2 concentrations, a long term target is essential (Meinshausen et al., 2009). GHG emission levels in 2050 are considered a good indicator of the likelihood of achieving the 2 °C target (O'Neill, Riahi, & Keppo, 2010). Therefore, the methodology outputs should go up to the year 2050.

2.1.2. Practicality

The goal of practicality ensures that the methodology is useful from a business perspective. Because companies often do not work on the time scale required for a useful climate target (i.e. 2050) the long-term targets should be translated into short-term targets that are in line with the long-term target. Furthermore, companies are known to have a preference for using both absolute emissions targets and emission intensity targets (Carbon Disclosure Project, 2008). The methodology should enable the setting of these two types of targets.

2.1.3. Verifiability

Considering that in the future NGOs might want to assess companies not only based on their GHG emissions (current performance), but also on their GHG emissions targets (future performance ambition), it is important to think of verifiability already in the development stage. To increase verifiability, the GHG emissions targets should be calculated based on publicly available data. The goals and their resulting methodology requirements are summarized in Table 1.

Table 1: Research goals and target requirements.

Goal	Target requirement
Environmental impact	1. Covering large companies
	2. Covering energy-intensive sectors
	3. Including all 6 Kyoto GHGs
	4. Including emission scopes 1, 2, and 3
	5. 2050 target
Practicality	6. Short-term targets
	7. Absolute targets and intensity targets
Verifiability	8. Based on publicly available data

Background Box 2: GHG emission scopes

In 1998, the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) launched the GHG Protocol Initiative. This partnership, consisting of NGOs, corporations, and institutes, strives to develop an internationally accepted accounting standard for GHGs (Greenhouse Gas Protocol, 2004). In the GHG Protocol Corporate Accounting and Reporting Standard, three different kinds of emissions are defined: scope 1, 2, and 3.

Scope 1: Direct emissions

Scope 1 emissions (or direct GHG emissions) occur from sources that are owned or controlled by companies. These emissions can be from fuel combustion or chemical processes (e.g. CO_2 emissions from the calcination reaction in cement production). Excepted from this scope are emissions from the combustion of biomass or GHGs that are not covered by the Kyoto protocol[3]. These emissions may be reported separately and are not included in scopes 1 to 3.

Scope 2: Indirect emissions from energy use

Scope 2 GHG emissions arise from the generation of purchased electricity, steam, heat or cooling. These are emissions that physically occur at another company, but are accounted to the company that uses the electricity, heat, steam, or cooling.

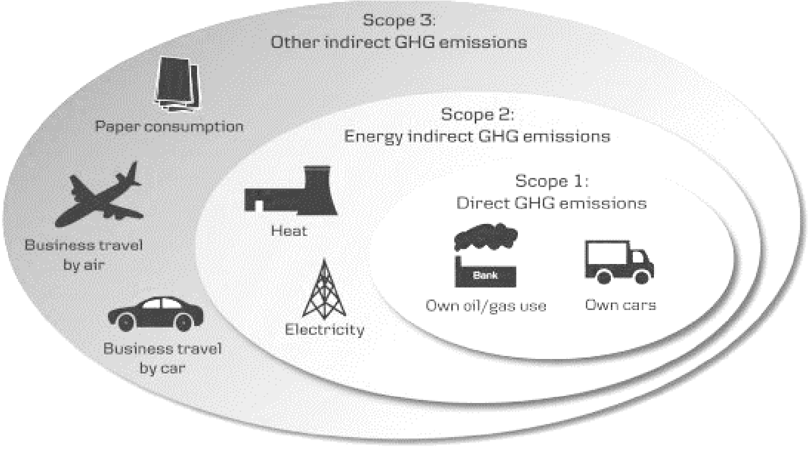

Figure 4: Different emission scopes (Olive Ventures, 2011).

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[3] The Kyoto protocol covers carbon dioxide (CO_2), methane(CH_4), nitrous oxide(N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6) (UNFCCC, 2008)

Scope 3: Other indirect emissions
Scope 3 is the most complicated scope in the GHG protocol. This scope covers all emissions that occur as a consequence of the company's activities, but are emitted from sources that are not owned or controlled by the company (for example, the emissions from use of an automobile are scope 3 emissions for an automobile manufacturer). Scope 3 emissions can occur upstream (e.g. manufacturing of products used by the company) or downstream (e.g. end-of-life emissions from waste management). Because scope 3 is a complicated category of emissions (because of issues with double counting, allocation etc.), the accounting standard for scope 3 emissions is still under development. Therefore, reporting scope 3 emissions is currently optional.

2.2. Conceptual methodology

In this section the conceptual methodology is developed using the goals and targets in Table 1. The starting point of the methodology is the 2 °C target. The 2 °C target is first translated into GHG emissions for the target year (section 2.2.1). The total GHG emissions budget for the target year is allocated to sectors (section 2.2.2). Then, the sectoral GHG emissions budget is allocated to the companies within that sector (section 2.2.3). Through backcasting, and applying the principle of convergence and contraction, the long-term target is translated into short-term targets (section 2.2.4).

2.2.1. Translating the 2 °C target to target year emissions

The process of starting with a desirable future and working backwards to identify the actions required to connect this future to the present is called backcasting (Dreborg, 1996). A simplified representation of the process of backcasting from the future that limits global warming to 2 °C is shown in Figure 5. First a stabilization level of radiative forcing (the warming effect) of GHGs for the very long-term is determined. In order to limit global warming to 2 °C, this radiative forcing should be limited to 2.6 W/m^2 (van Vuuren, Stehfest, et al., 2011). This radiative forcing implies a certain total carbon budget for the coming century. The carbon budget is spread out over the years in a feasible way using integrated assessment models (Meinshausen et al., 2009). Both the cumulative emissions up to 2050 and the emissions level in 2050 are found to be robust indicators of the probability to limit global warming to 2 °C (Meinshausen et al., 2009; O'Neill et al., 2010). Therefore, looking at the period 2010-2050 is appropriate for this thesis.

In Figure 5, the annual carbon budgets for the years up to 2050 are allocated to sectors A, B, and C. This first allocation step is described in section 2.2.2. In this example, only three sectors are distinguished. Ideally, the amount of sectors should be as high as possible to ensure sector homogeneity (although in practice the amount of sectors that can be distinguished is limited due to data limitations). Note that in Figure 5, the sectoral pathways differ significantly. While Sector A shows a modest decline in GHG emissions, followed by a steep decline, Sector C shows an emissions growth, followed by a steep decline. This is caused by sectoral differences (e.g. in production growth, technological abatement possibilities and equipment lifetimes).

When the sectoral GHG emission pathways are constructed, the second allocation step divides the sectoral carbon budget for a year over the companies in that sector. Using company-specific information, the company GHG emission pathway is created. Each point of this pathway can be considered a GHG emissions target that is in line with the 2 °C global warming target. The second allocation step is described in section 2.2.3.

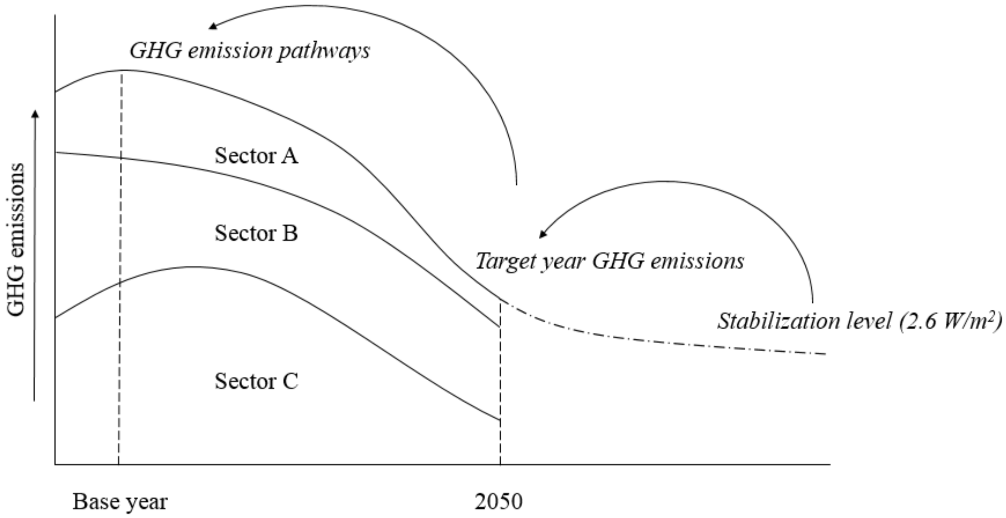

Figure 5: Simplified representation of the backcasting method used.

2.2.2. Allocating global emissions to sectors

The global carbon budget that keeps global warming under 2 °C can be allocated to sectors in different ways. Girod, van Vuuren, & Hertwich (2013) distinguished the following allocation options that can be used to allocate mitigation efforts to sectors:

- Base year: allocation of allowed GHG emissions proportional to their share in GHG emissions in the base year.
- Same reduction: applying the same GHG emission reduction percentage (on a per-unit-of-activity basis) to all sectors.
- Same costs: GHG emissions are abated while minimizing overall costs. The marginal abatement cost is calculated for each sector, and a global carbon emission tax is applied to the integrated calculation model.

Of the three options above, base year allocation is considered the least fair, because future emissions are entirely based on current performance. If a sector is already very carbon efficient (and thus has relatively low GHG emissions), it is allocated a low share of future emissions. Meanwhile, a sector that is very carbon intensive gets awarded a larger share of future emissions, resulting in a lack of incentive for implementing abatement measures. Furthermore, this method is heavily influenced by the chosen base year. If, for example the iron market was affected by a crisis in the base year, the iron sector is disadvantaged and gets awarded a very low amount of GHG emissions in the future.

The second option seems fairer at first sight. If every sector reduces its GHG emission intensity with the same percentage, the iron sector in the example above had a low amount of emissions due to low production, but the carbon intensity of its products are the same nevertheless. Furthermore, the carbon intensive sectors need to reduce more absolute emissions than the less carbon intensive sectors. This seems fair, because a large emitter logically is able to potentially reduce more emissions. However, in some sectors, a (large) share of GHG emissions cannot be avoided. In cement production, for example, the calcination reaction produces large amounts of CO_2 (around 54% of total CO_2 emissions from cement production) (McKinsey & Company, 2009a). These CO_2 emissions are inherent to cement production and partially the reason for this sector being carbon intensive (IEA, 2012a). This issue can be tackled by excluding process emissions, but this creates additional issues (the methodology would not be consistent with the GHG protocol, and no incentive is created for investigating the use of other processes, substitute products, or recycling). Same reduction allocation does not take sectoral differences into account and results in a sub-optimal economical outcome.

The third option optimizes the GHG emissions reduction on least-cost. This makes sure that the most cost-efficient abatement measures are used and that the costs to society as a whole are as low as possible. However, this could mean that one country or sector is supposed to invest more in abatement measures than another sector or country. So although same cost allocation ensures that emission reductions are possible and effective, it is not fair from an economic perspective. However, policies can be imagined that solve this issue and redistribute the economic burden. A carbon tax, for example, puts a price on CO_2 emissions. If the price that needs to be paid for emitting a tonne of GHGs is high enough, companies reduce their emissions where it is cheapest (IPCC, 2014c). Some companies already use a carbon price for investment decisions, thereby anticipating the future implementation of a carbon tax (CDP, 2013b).

Considering that this methodology is designed for setting voluntary corporate climate targets, and that companies themselves already anticipate for future policies like a carbon tax (Boiral, 2006; Dean, 2013; Hoffman, 2004; Kolk & Pinkse, 2004), same cost allocation is used to allocate emissions to sectors. However, choosing such an approach requires vast amounts of data on individual technologies, economical parameters such as price elasticity of demand, and copious assumptions about future developments. There are studies that have developed scenarios that allocate GHG reduction burden among sectors using same cost allocation. These are discussed in section 4.2.

2.2.3. Allocating sector emissions to companies

After the GHG emissions in the target year are allocated to the sectors, the sectoral GHG emissions are allocated to the different companies within that sector (see Figure 6). This allocation can be done in several ways, effectively resulting in sector intensity targets (Randers, 2012):

- By number of employees or fulltime-equivalent (FTE) (equal amount of GHG/employee or GHG/FTE in sector).
- By revenue (equal amount of GHG/revenue in sector).
- Same costs (equal amount of GHG/abatement in sector)
- By activity (equal amount of GHG/unit of activity in sector)

Allocating by number of employees (or by number of FTE to account for part-time workers) results in a rather arbitrary method, because the number of employees do not necessarily correlate to GHG emissions. A highly automated car manufacturer gets awarded less GHG emissions than a car manufacturer that shows less automation and more employees. This does not necessarily mean that the automated car manufacturer should have less GHG emissions (and perhaps even more GHG emissions are expected resulting from energy use). Furthermore, the automated company might even produce more cars and more efficiently.

Allocating by revenue seems fairer than allocating by number of employees. A large company typically has high revenues and high GHG emissions. However, cases can be imagined where it is not fair at all. For example, a car manufacturer that manufactures 100 luxury sports cars has high revenues with a small number of cars produced, while a car manufacturer that makes 10,000 cheap small cars might have similar revenues. The amount of GHG emissions from these two companies (although in the same sector) is probably not comparable.

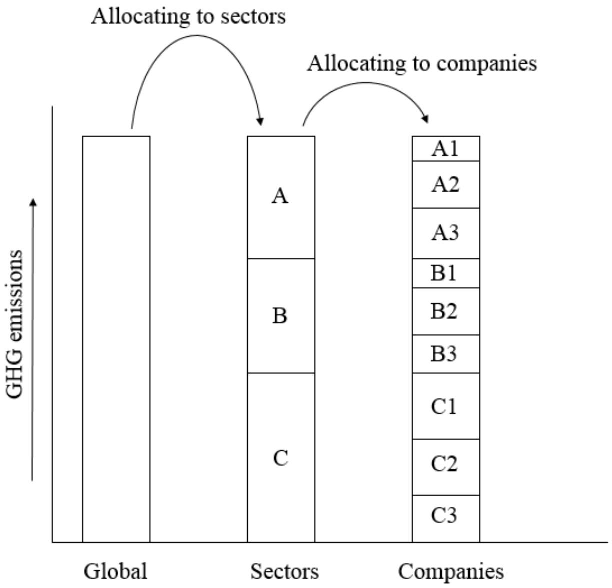

Figure 6: Simplified representation of the two-step allocation of global GHG emissions to companies in a given year.

The same costs allocation method described in section 2.2.2 can theoretically also be used to allocate emissions to individual companies in the sector. This method would be ideal because it would result in internal consistency in the methodology, and it would completely minimize costs. However, its major disadvantage is the requirement of extensive amounts of company-specific information. Figure 3 in Background Box 1 already showed that with such a low level of aggregation, data availability is problematic. Furthermore, the amount of assumptions that one must make to adequately model future costs of abatement on a company level result in unacceptable uncertainties.

Allocating by activity means that a company that performs 2% of the activities in a sector (e.g. produces 2% of global crude steel) is allowed to emit 2% of the sectoral GHG budget. This allocation principle ensures that the useful output from the company (the product or service) is linked to the negative output (GHG emissions). However, several indicators for corporate activity are used. A distinction can be made between physical and monetary units of activity. Annual sales or annual VA are examples of monetary activity indicators (Randers, 2012). The amount of units produced or the amount of goods transported are examples of physical activity indicators. Both kinds of activity indicators have their advantages and disadvantages. For monetary activity indicators, the main advantages are good data availability and measurability, and that they can easily be used for heterogeneous sectors. For example, sales figures are easily available through financial statements and can easily be compared among sectors (Girod, van Vuuren, & Hertwich, 2013b).

For physical activity indicators, such a comparison is often difficult. Furthermore, physical indicators cannot be used for heterogeneous sectors. For example, the chemical industry has a wide range of useful outputs, making it impossible to pick one product as the activity indicator. However, Girod et al. (2013b) found there are also clear advantages to using physical indicators. First, it is often easier to interpret GHG emission intensities that use physical indicators. Most people are able to comprehend, for example, the amount of annual GHG emissions per m^2 floor space, whereas the annual GHG emissions per dollar revenue is a very abstract representation of a housing cooperative's GHG intensity. Second, the physical units are more directly related to GHG emissions. Girod & De Haan (2010) found that monetary indicators both capture changes in physical amount and quality. However, it is primarily the change in physical amount that causes the GHG emissions. Therefore, using monetary indicators for activity results in perverse incentives: decreasing the GHG emissions per monetary unit with 5% can be done either by reducing GHG emissions with 5%, or by increasing prices with 5.3% (thus not affecting actual GHG emissions). Third, physical units are able to capture saturation trends in production. While there is a limitation to the physical amount of iron that can be produced (due to scarcity and market saturation), there is no clear limit on the value of that amount of iron (Girod et al., 2013b).

Finally, variations in monetary indicators are affected by changes in factors as costs and product prices (Wilson, Trieu, & Bowen, 1994). An unwanted effect of this is that a sudden price hike may lead to changes in monetary activity, while the physical activity is constant (Farla, 2000). This fluctuation in monetary GHG emission intensity is also seen in monetary energy intensity (Figure 7). While the physical energy intensity of cement production in the years 1988-1992 did not see significant changes, the monetary energy intensity fluctuated heavily because of other factors that are included in the monetary activity indicator (Freeman, Niefer, & Roop, 1996).

Because of the advantages of physical activity indicators, the allocating of sectoral GHG emissions to companies in that sector is preferably done based on a company's share in activity. However, the physical data is often not available. In the cases where physical data is not available, a monetary indicator of activity is considered the best alternative. Another disadvantage of using a physical activity indicator is that it is only functional if the sector is homogeneous. In the chemical industry for example, a wide variety of different products are produced in different processes resulting in different amounts of GHG emissions. In that case, using a physical indicator would be unfair towards companies only active in producing carbon-intensive products. Therefore, notwithstanding the disadvantages of monetary indicators, for heterogeneous sectors, a monetary indicator is considered the best available activity indicator.

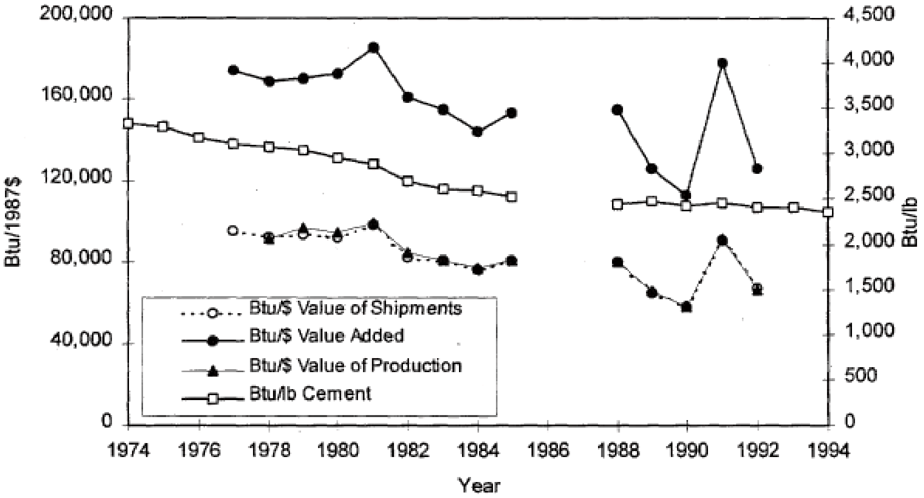

Figure 7: Monetary and physical energy intensity of cement production (Freeman et al., 1996).

When carbon offsetting[4] is combined with allocation by activity, the market will theoretically allocate the abatement in the most cost-effective way. Although the offset market is currently complex, uncertain, and unstable, once well-regulated it could theoretically be the solution to the sub-optimal outcome of the allocating by activity (Lovell, Bulkeley, & Liverman, 2009).

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[4] The practice of compensating for GHG emissions by reducing GHG emissions elsewhere

2.2.4. Contraction and convergence

After allocating to sectors and then to companies, the company target for the target year is determined. In this thesis, the target year is 2050 in order to fulfil requirement 5 from Table 1. The next step is to determine the pathway that leads to the 2050 target. That pathway is determined using the company's current performance and applying the contraction and convergence principle.

The concept of contraction and convergence is first coined by Meyer (2000) as a fair approach to share climate change mitigation efforts. The first step in the approach is to determine a path of future emissions and a long-term stabilisation target. This contraction step is already taken in section 2.2.1 by setting the long-term 2050 GHG emissions target. The next step in the approach is to set targets for all countries in a way that per capita GHG emissions converge from their current level towards a future level that is equal for all countries (Hagemann, Höhne, & Fekete, 2013). Instead of focusing on the question of how to share the burden of reducing GHG emissions, this method starts from the assumption that the atmosphere is a global common good that belongs to everyone. This implies that the emission rights are divided over the global population (Kuntsi-Reunanen & Luukkanen, 2006). The contraction and converge principle is converted to its application in corporate target-setting by using GHG emissions per unit of activity instead of GHG emissions per capita.

Figure 8 shows how the GHG emission intensities of companies A, B, and C are different in the base year. The sector average line shows the contraction to a lower GHG emission intensity in the sector. All the individual companies are required to converge to that same level of GHG emission intensity. Note that the sectoral average intensity pathway is linear in this example, but can be curved depending on the underlying scenario results. This curvature would be translated to the company pathways, since their convergence is towards the sectoral pathway, and not just the 2050 target.

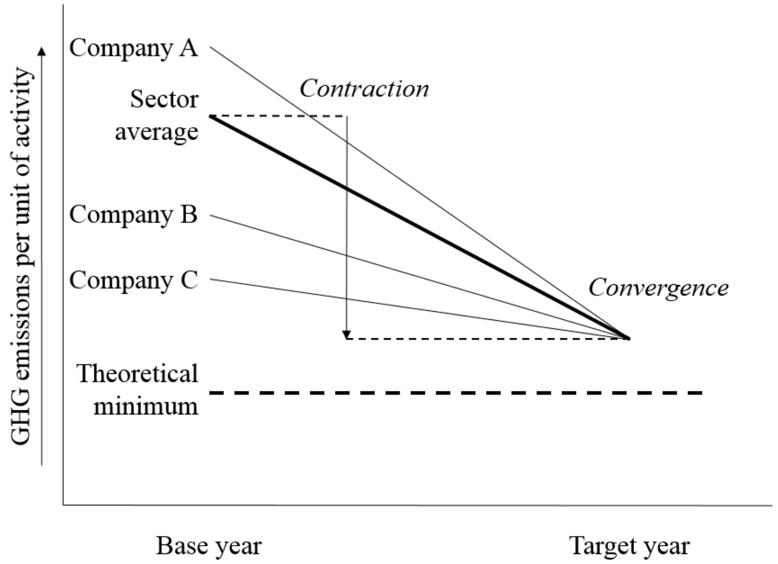

Figure 8: The contraction and convergence principle applied to companies within a sector.

Also shown in Figure 8 is the theoretical minimum level of GHG emissions per unit of activity. This minimum is often due to process emissions (as in the cement example from section 2.2.2) that cannot be avoided. However, carbon dioxide capture and storage (CCS) or carbon offsetting could lower the theoretical minimum for several sectors (IEA, 2012a; IPCC, 2014c).

In order to construct a company GHG emission pathway, the base year GHG emission intensity is required. This information is not available for all companies (e.g. a new entrant does not have any historical GHG emissions). These companies can use the sector average as a target (or set a target once they know their GHG emissions), and do not pose a threat to the 2 °C target, because their production is considered a substitution of production in another company, not changing total production by the sector.

Note that all companies are treated the same, not accounting for geographical location. Although this seems unfair, because the developed countries will have emitted more of the carbon budget than developing countries, in fact, this method enables growth in developing countries. For example, a company in India can grow as long as its intensity converges to the target value in 2050.

2.2.5. Sectoral intensity target approach to corporate GHG emission target setting

Combining the sectoral intensity pathways using the two consecutive allocation steps with the convergence of company intensities to this sectoral target creates what is named the Sectoral Intensity Targets Approach (SITA). The SITA method requires input data on two levels. The first level is the global GHG emission scenario level. Ideally, an IAM is used to create a scenario that meets the 2 °C target. The scenario requires sectoral detail and bottom-up technology modeling to assess the costs of abatement measures. Future demand is modeled using assumptions about global population growth, GDP growth, and fuel price changes. The scenario optimizes on least-cost and allocates emission reductions to the sectors according to the method described in section 2.2.2. The sectoral GHG emission pathways and the total sector activity data necessary for the allocation to companies within sectors are retrieved from the scenario.

The second level of input is the company specific data of the company for which a target is set. First, the company is assigned to a sector. If a company is active in several sectors, the company (and its GHG emissions and activities) can be divided into parts that get appointed individual targets[5]. Second, a base year is selected for which GHG emissions and activity data is available. The GHG emissions (calculated following the GHG protocol) and activity in the base year are required. Finally, the expected activity in the target year can be used to convert the GHG emission intensity target for that year into an absolute emissions target. This is however optional, and there must be noted that the GHG emission intensity target is binding for the 2 °C target, because a company activity prediction comes with major uncertainties.

Figure 9 shows how the inputs are used in the SITA calculation. The information from the GHG emission scenario is used to construct sectoral GHG emission intensity pathways. The information from the company is used to calculate the GHG emission intensity of the company in the base year. The company intensity pathway is then constructed by converging the company base year GHG emission intensity towards the sectoral GHG emission target. The company intensity pathway can be considered as a collection of points that represent GHG emission targets that are in line with the 2 °C target.

The SITA method as presented in Figure 9 meets all requirements (req.) from Table 1 as long as the scenario covers: all sectors that include large companies (req.1); all energy-intensive sectors (req.2); all 6 Kyoto GHGs (req.3); and all scope 1, 2, and 3 emissions (req.4). Furthermore, the company must know all its scope 1, 2, and 3 GHG emissions (req.4). Finally, all this information must be publicly available to ensure

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[5] When dividing company GHG emissions over business units, allocating general GHG emissions to these business units might be necessary. The methodological choices made in this allocation should be according to the principles of the Greenhouse Gas Protocol (2004).

verifiability (req.8). The resulting intensity targets originate from a 2050 target (req.5), are translated to short-term targets (req.6), and can be converted to absolute targets using activity expectations (req.7).

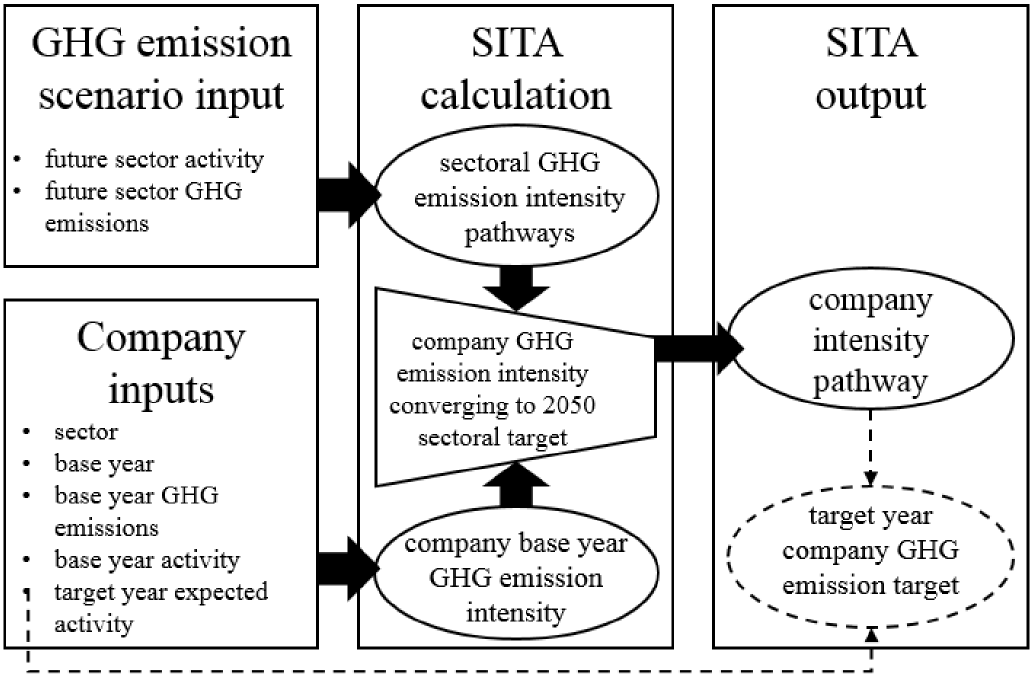

Figure 9: Schematic representation of the SITA methodology.

2.2.6. Calculating corporate emissions targets

Before a company can calculate its emission targets, it needs to determine in which sector it is active. If the company is active in multiple sectors, it needs to properly allocate its emissions to the different sectors. Next, the company can calculate its GHG emission intensity targets until 2050 using the following equation:

$$CI_y = IF\left(\max\left(SI_y - \left(\frac{SI_b - CI_b}{t-b}\right) * (t-y), CI_t\right) < CI_{y-1},\ \max\left(SI_y - \left(\frac{SI_b - CI_b}{t-b}\right) * (t-y), CI_t\right), CI_{y-1}\right) \qquad \text{(Equation 1)}$$

Where:

CI_y = Company GHG emission intensity in year y
SI_y = Sector GHG emission intensity in year y = from sectoral intensity pathway
t = target year = 2050
b = base year = chosen by company (year after 2011)
y = year for which the company GHG emission intensity is calculated

Required inputs for the calculation are the sectoral intensity pathways derived from a scenario, and GHG emissions and activity data for the chosen base year. If a year b or y is chosen where no sectoral GHG emission intensity is provided for by the scenario, the value for that year is to be determined using linear interpolation.

Equation 1 effectively converges the company GHG emission intensity towards the sectoral pathway by calculating the difference in the base year, and reducing the difference by the same amount every year until the difference is zero in 2050. In order to avoid company pathways that prescribe a growth in intensity, two constraints are included. If the calculated value for a year is higher than that of the year before, the intensity remains the same. If the calculated value for a year is below the 2050 target, the prescribed intensity is equal to the sectoral 2050 intensity.

2.3. Literature review

Before the conceptual method is tested, other existing GHG emission target-setting methodologies are reviewed. This is necessary to assess to what extent the SITA method is an improvement.

Literature is searched using online search engines Scopus, Google Scholar, and Google. Various search strings and combinations of search strings are used (such as “greenhouse gas emission target AND ALL company OR ALL corporate”). Based on the results from search engines, more search strings are used. The list of existing target-setting methodologies is presented to Ecofys, who discussed it with experts in the field to minimize the chance of accidentally excluding an existing methodology. Most of these experts developed target-setting methodologies themselves and work for companies (e.g. BT, Ford, Autodesk or Mars) or NGOs (e.g. WWF, CDP, Carbon Trust or WRI) that are interested in improving current target-setting practices.

The GHG emission target properties distinguished in the first part of the literature review are used to compare the GHG emission target-setting methodologies found in the second part of the literature review to assess whether SITA improves or complements the existing methodologies. The literature review is presented in chapter 3.

2.4. Sectoral intensity targets

After the literature review, SITA is first complemented with a scenario that allocates GHGs to sectors and includes sectoral activity projections. An existing scenario is used for this. First, a scenario is selected using multi-criteria analysis (MCA). Then, the selected scenario is studied further to assess which sectors can be distinguished and what their activity indicators are. Then, the sectoral intensity pathways are constructed. Finally the sectoral intensity pathways are analysed for feasibility and practical implications. The sectoral intensity targets are constructed and analysed in chapter 4.

2.5. Case studies

The next step is to apply the SITA methodology on companies. Case studies are used to test whether the methodology meets the requirements and goals from Table 1 on the company level. The case studies are presented in chapter 5.

2.6. Sensitivity analysis

In order to assess the effects of the choices made in both developing the methodology and choosing data sources, a sensitivity analysis is conducted. Using the results of the case studies as a baseline, the targets are recalculated with different inputs and the change in the resulting targets is analysed. The sensitivity is analysed in chapter 6.

3. Literature review

Over the past decades, interest has grown among companies to reduce their carbon footprint. These so-called voluntary commitments are mostly driven by the rising cost of energy, stakeholder and consumer pressure, and the expectation that governments will continue to implement GHG reducing policy measures (Gouldson & Sullivan, 2013). In order to promote GHG emission reductions, companies set GHG emission targets. Although there are conventions regarding the measuring and reporting of carbon emissions, there are none for target-setting. This lack of a standard results in targets that are not consistent, do not account for reduction potential and are implemented for marketing reasons instead of environmental reasons (McKinnon & Piecyk, 2012). This section describes the methods that are developed to set GHG emission targets.

Automobile manufacturer Ford sets science-based CO_2 targets. These targets are based on analysis with the global energy transition model (Grahn, Klampfl, Whalen, et al., 2013). Using the output of a model that allocates emission reductions on the same costs principle, and using a 450 ppmv CO_2 constraint, carbon intensity glide paths (similar to the SITA intensity pathways) are constructed up to 2030, however the specific calculations behind their method are not public. As results are only modelled for CO_2, other GHGs are excluded from their glide paths. These glide paths do not represent their direct carbon emissions, but the emissions resulting from their products (scope 3). This is an effective target because in the automotive industry, most carbon is emitted during the use phase (Ecolane Transport Comsultancy, 2006; Renault, 2011). Although this approach is very effective for Ford (and for other automobile manufacturers), it is not a method that can easily be applied to other sectors. Depending on the method of calculating company-specific glide paths from the model output, this method might be considered complex.

Confectionery manufacturer Mars set their climate targets based on what the IPCC agreed to be necessary to keep global warming below 2 °C. From the 80% reductions by 2050 recommended by the IPCC, Mars derived their own targets: eliminating scope 1 & 2 GHG emissions (except emissions from the company cars) and reducing scope 3 emissions throughout the supply chain (Mars, 2013). The targets are not intensity-based, but absolute, and therefore do not allow for growth. Although this target works for Mars, this is not an approach that works for every company, because of the same-reduction allocation principle. For emission-intensive production processes, 80% reduction might not be possible. If all companies were to implement this method, it would be a very costly way of meeting the 2 °C target because it neglects differences in emission abatement costs in different sectors (Grahn et al., 2013). However, for the companies for which this method is feasible, it is a very simple and effective method.

Telecommunications service company BT's Chris Tuppen cooperated with Jørgen Randers of the Norwegian School of Management to develop a target-setting approach that is more general in nature: the Climate Stabilization Intensity (CSI) Target (Tuppen, 2009). The CSI target is based on a carbon intensity per VA. In order to meet the 80% reduction target in 2050, and assuming a global annual GDP growth rate of 5.9%, this intensity is supposed to be reduced by 9.6% annually. It is unclear if this method is for scope 1, 2, or 3 emissions. Because it uses an intensity, the target allows for growth. This method of target-setting is simple, applicable to all companies, and would result in achieving the 2 °C target. However, it is not the most cost-effective way of GHG emission reduction, and the annual same-reduction of 9.6% might not be possible for some industries (e.g. cement or aluminium) due to theoretical limits.

Software developer Autodesk based their Corporate Finance Approach to Climate-stabilizing Targets (C-FACT) on the CSI method. Autodesk uses gross profit as a proxy for the company's contribution to GDP. A company's GHG emissions are divided by its gross profit to calculate the intensity, and the target is a 85% reduction for developed countries, and a 50% reduction for developing countries in 2050 (Stewart & Deodhar, 2009). This is fairer than the CSI method towards developing countries, because they do not emit as much GHGs as the developed countries. However, energy intensive sectors are still treated the same as other sectors and this results in higher total abatement costs.

ICT company EMC used the C-FACT method to determine their emission reduction target. However, where the C-FACT method reduces carbon intensity with the same percentage each year, the EMC method uses a different path to reach the same 80% reduction in 2050. The difference between the C-FACT and the EMC pathway is shown in Figure 10. The EMC pathway consists of increasing reductions until 2030, thereby delaying the emission reduction measures, making it a more lenient target (EMC, 2014).

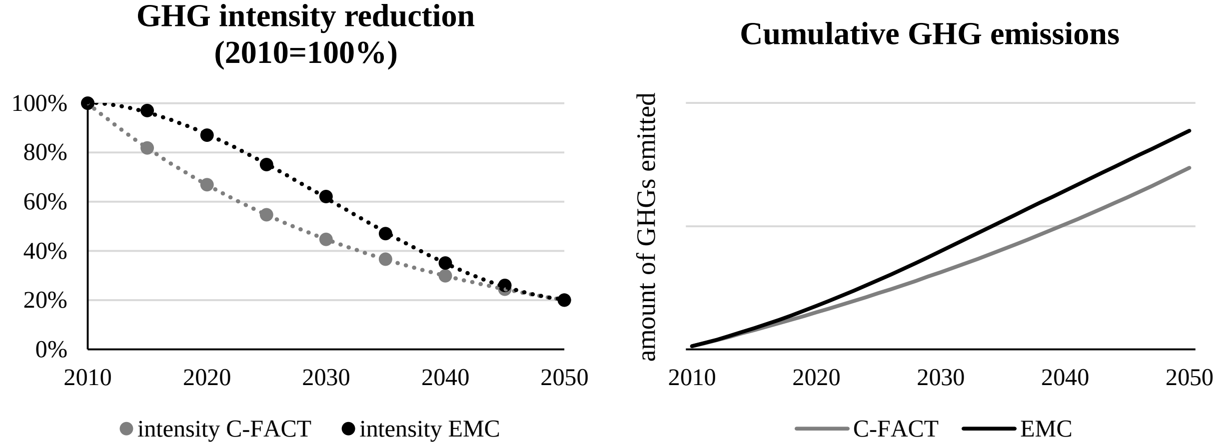

Figure 10: Differences in intensity pathways and absolute emissions pathways C-FACT and EMC.

Although EMC's pathway is more realistic as it is accounting for learning effects (Pan & Köhler, 2007), it uses a larger carbon budget to reach the 2050 target (see right graph in Figure 10). The cumulative amount of GHGs emitted until 2050 under the C-FACT method is already emitted in 2044 when the EMC method is used. If every company were to use this method the increased carbon budget (as compared to the regular C-FACT method) would have a significant climate impact.

Other organizations such as NGOs and government agencies are also promoting voluntary climate action in companies. The U.S. Environmental Protection Agency (EPA) has developed a benchmarking tool as part of their Climate Leaders Partnership programme. The purpose of this tool is to determine the amount of emission reductions in a business-as-usual scenario. The scenario is constructed using an input-output table with 200 sectors and extrapolating historical carbon intensity trends into the future (Tonkonogy & Sullivan, 2007). In their Climate Savers programme, WWF uses a similar method (developed by Ecofys) to assess the impact of their programme (Ecofys, 2012). These bottom-up targets make distinctions between sectors, but they are not in line with the 2 °C target.

In their 3% solution (3%S) report, WWF and CDP present a method to calculate a 2020 GHG emissions target. A sectoral approach is used to determine sector reduction opportunities and sector emissions change projections. These are then used to calculate a GHG emission target for a company based on its current emissions and its growth ambition (CDP & WWF, 2013). This method combines bottom-up sectoral estimates with top-down growth expectations to create a feasible target that is in line with a “reasonable chance” (as stated in the 2007 IPCC AR4) of averting warming above 2 °C. However, because the methodology sets targets for 2020, the bulk of GHG emission reductions required for the 2 °C target are not captured in the target. The method focusses on the U.S., so the sectoral abatement potential and business-as-usual (BAU) abatements are for the U.S. only. According to the report, the emissions can be reduced while saving costs. A downside of this method is that all companies in a large aggregated sector are expected to reduce their emissions with the same percentage. For some industries within the sector this might be impossible because of the theoretical minimum (e.g. cement production). Furthermore, expanding this method to a global coverage would require extensive in-depth research for every country and sector.

While there is a significant amount of corporate and NGO attention for corporate GHG emission target-setting methods, there is less scientific literature on the topic. One peer-reviewed article proposes a corporate GHG emission target-setting methodology. The method is named the greenhouse gas emissions per unit of VA (GEVA) method (Randers, 2012). It is developed by Randers after he co-developed the CSI method for BT mentioned earlier. The main difference between GEVA and CSI is that GEVA is not based on the emissions and the VA in the base year, but on the GEVA trend over 5 years. This solves the problem of VA fluctuations severely impacting climate targets. Furthermore, only scope 1 is included in order to avoid double counting and to make it possible to add up the company emissions to national emissions. By neglecting scopes 2 and 3, Randers’ method causes perverse incentives, like using a lot of electricity for heat applications to reach the target (which results in higher overall emissions) or neglecting energy efficiency improvements in products (e.g. cars or refrigerators). Randers (2012) suggests that his GEVA method be differentiated to account for geographical differences.

A recent report from Climate Counts and the Center for Sustainable Organizations presents a new sustainability indicator that assesses a company’s GHG emissions: the context-based metric (CBM). In order to make this assessment, the methodology defines sustainable emissions (Climate Counts & Center for Sustainable Organizations, 2013). This methodology can be transformed into a GHG emissions target-setting methodology by using its definition of sustainable corporate GHG emissions and projecting that into the future. To construct the context-based metric, intensity targets are retrieved from a GHG emissions scenario (at first release, the PoleStar Project Policy reform scenario (Raskin, Banuri, Gallopin, et al., 2002), and in a later update, RCP2.6 (van Vuuren, Stehfest, et al., 2011)). By following a scenario, the likelihood of achieving the 2 °C target is higher than in other methods. However, the method uses VA as its activity indicator, resulting in the problems previously mentioned. Furthermore, their approach is strongly influenced by the company’s base year performance and the calculations and reasoning behind it are not properly explained (McElroy, 2013).

The different methods and their characteristics are listed in Table 2. Based on this literature overview, it can be concluded that the amount of attention from companies and NGOs for the topic of emissions target-setting methodologies is relatively high, but overall the field is new and underdeveloped. Scientific literature on this topic is limited to one method. All of the methods found have their shortcomings. Some are limited in their coverage of different scopes of emissions and different included GHGs, others do not allow for growth and only one method uses a physical activity indicator to allocate GHG emissions. Two methods developed by companies are not generic methods, but they might be converted to generic methods.

Table 2: Differences between emission target-setting methods.

Aspect	Method							
	Ford's	**Mars'**	**CSI**	**C-FACT**	**EMC's**	**3%S**	**GEVA**	**CBM**
Generic/ specific	Specific	Generic	Generic	Generic	Specific	Specific	Generic	Generic
CO_2/GHG	CO_2	GHG	GHG	GHG	GHG	GHG	CO_2	GHG
Scope	3	1,2&3	1&2	Unknown	1,2&3	1&2	1	1&2
Time frame	To 2030	To 2050	To 2050	To 2050	To 2050	To 2050	To 2050	To 2050
Physical/monetary intensity or absolute	Physical intensity	Absolute	Monetary intensity	Monetary intensity	Monetary intensity	Absolute	Monetary intensity	Monetary intensity
Verifiable	No	Yes	Only if VA is public	Only if VA is public	No	No	Only if VA is public	Only if VA is public
Allowing for growth	Yes	No	Yes	Yes	Yes	No	Yes	Yes
Sector discrimination	Yes	No	No	No	No	Yes	No	No
Allocation principle	Same costs	Same absolute reduction	Same intensity reduction	Same intensity reduction	Same intensity reduction	Same costs	Same intensity reduction	Same intensity reduction
Simplicity	Complex	Simple	Simple	Simple	Simple	Simple	Simple	Complex

The following conclusions can be drawn from the literature review:

- All found methodologies except for Ford’s, the 3%S, and EMC’s can be applied to large companies (req.1), including energy-intensive sectors (req.2). However, for some energy-intensive sectors, the targets may not be feasible.
- Two of the methodologies cover only CO_2 emissions (i.e. Ford’s and GEVA) and the rest can theoretically cover all GHGs of which the company has sufficient data (req.3).
- Two methods cover all three emission scopes (i.e. Mars’ and EMC’s), Ford’s method only scope 3, three methods scope 1 and 2, and GEVA only scope 1 (req.4).
- All but Ford’s method are derived from a 2050 target (req.5).
- All methods translate a long-term target to short-term targets needed for business decisions (req.6).
- Two methods use an absolute target, five methods a monetary intensity target, and one (Ford’s) uses a physical intensity target (req.7). The intensity targets can be converted to absolute targets using activity predictions.
- Only three methods use publicly available data (i.e. Mars’, CSI, and C-FACT) (req.8).
- No single existing methodology meets all requirements.

Mars’ method meets most of the requirements (all except req.7). However, their target is far too stringent, it does not allow for growth, and does not discriminate between sectors. Furthermore, its allocation principle results in extremely unfair targets. The monetary intensity approaches are similar and are often not verifiable. Furthermore, they use the same intensity reduction allocation method, with the before mentioned disadvantages. The 3%S and Ford’s method use a bottom-up approach based on techno-economic modelling that uses the same costs principle. However, these methodologies are not verifiable, and only cover the U.S. and passenger vehicles, respectively.

Since the SITA methodology meets all requirements (ideally, see section 2.2.5.), the SITA method can be regarded an improvement to existing methods. The SITA method adds the sectoral detail of the 3%S method and Ford's method to a global, more generic approach like the monetary intensity approaches. Ford's approach shows that a scope 3 target can be very useful to effectively reduce GHG emissions of product use. However, in practice, measuring scope 3 emissions is problematic for most sectors (this is probably the reason Ford only sets targets for certain downstream emissions), and therefore problems with data availability are expected.

The analysis of the difference between EMC's method and C-FACT shows the importance of looking at the carbon budget instead of just a 2050 target. Therefore, the carbon budget of the selected scenario is assessed in chapter 7.

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4. Sectoral intensity targets

4.1. Complementing the conceptual SITA method

The sectoral approach to fair emissions targets aligns the emissions targets for companies with an existing 2 °C scenario. The selection of this scenario is an important step in the development of the SITA method. The scenario selection is described in section 4.2. In order to divide the mitigation effort in a fair way, the targets are sector-based intensity targets. The sectors and activity indicators are defined in section 4.3. Using the scenario data for each sector, and combining it with additional data where necessary, emissions pathways are created. The way these pathways are calculated is described in section 4.4. The resulting sectoral targets are analysed for feasibility and practical implications in section 4.5.

4.2. Scenario selection

Over 1,000 different GHG emission scenarios have been developed that show possible energy futures (IPCC, 2014c). The scenarios differ in their assumptions, scope, level of detail, time frame and level of scientific robustness (Krey & Clarke, 2011). In order to select a scenario that is suited for use in the SITA method, first, an overview is presented of energy scenarios that have been developed by different scientists, companies, NGOs and institutes. Second, an illustrative set of scenarios is selected for further assessment. Third, the desired scenario characteristics are defined. Fourth, one scenario is chosen out of the illustrative scenarios using MCA to be the basis of the methodology. Finally, chosen scenario specifics are checked with other scenarios to assess the impact of scenario selection.

4.2.1. Greenhouse-gas emission mitigation scenarios

Emissions scenarios are descriptions of potential future emissions of substances into the atmosphere that have an impact on the radiative forcing (Moss, Edmonds, Hibbard, et al., 2010). Mitigation scenarios are emissions scenarios that emit less warming gases into the atmosphere compared to a BAU scenario. Mitigation scenarios are modelled using complex IAMs, combining knowledge about technologies, economics and the environment. Krey & Clarke (2011) reviewed 162 scenarios and their differences and similarities. They concluded that by combining the research of a large community exploring long-term mitigation they distilled valuable lessons, but there is a need for researchers comparing scenarios across studies and models in order to better understand uncertainties. In their 2011 report *"Bridging the emissions gap"* UNEP compared results of IAMs that were optimized on least cost towards a 2 degree target (UNEP, 2011). Although their results showed similarities between models and scenarios, they also reported significant differences in the outcomes. The IPCC also reviewed 164 scenarios they received through an open call for scenarios containing renewable energy modelling (IPCC, 2012). They used the combined results from the scenarios to give a comprehensive overview of the role of renewables in the future energy system in a similar fashion as Krey & Clarke (2011).

Although this was an effective method for their purpose, such an aggregated approach (e.g. using the average results to estimate targets) would not work for this thesis, because an average scenario would not necessarily reach the 2 °C target. Therefore, another approach (also used by IPCC (2012)) is used. A set of illustrative scenarios is chosen that differ in assumptions, goals and underlying models. These scenarios cover the wide range of scientific scenarios, and scenarios from institutes, consultancies, and NGOs. The selection is based on input from two scholars in the field of climate scenarios[6].

IPCC's RCP2.6

Emissions scenarios have been used by the IPCC ever since their first assessment report in 1990 (SA90), after which they were regularly updated and improved (Moss et al., 2010). In 2000, the so-called SRES scenarios were presented, and they have been used extensively for a decade (van Vuuren, Riahi, Moss, et al., 2010). By combining the latest knowledge at the time, the IPCC created a new set of scenarios: the Representative Concentration Pathways (RCP) scenarios (van Vuuren, Edmonds, Kainuma, et al., 2011). They are based on newly developed, more detailed knowledge and are more integrated with other disciplines (van Vuuren et al., 2010). The four RCP scenarios are peer-reviewed and (as suggested by Krey & Clarke) designed to represent scientific literature (van Vuuren, Edmonds, et al., 2011). The RCP scenarios are used in the IPCC's latest assessment report (AR5) of working group III, which was released in April 2014 (IPCC, 2014b).

The RCP2.6[7] scenario represents a pathway that limits global warming to 2 °C. RCP2.6 is a scenario that describes the scientific consensus of what a 2 degree scenario should look like (van Vuuren, Stehfest, et al., 2011). An important assumption made in the RCP2.6 scenario is that bioenergy combined with carbon capture and storage (BECCS) is a viable technology in the future. Without this assumption, a steep emissions decline (and thereby, reaching the 2 °C target) is not possible. The scenario is created using the IMAGE model (Bouwman, Kram, & Goldewijk, 2006). The energy demand is modelled using the TIMER sub model, which makes a distinction between five sectors: industry, transport, residential, services, and other (de Vries, van Vuuren, den Elzen, et al., 2001). The scenario gives annual outcomes until 2100 and uses the year 2000 as its base year.

LIMITS' RefPol-450

The LIMITS research project (Low climate Impact scenarios and the IMplications of required Tight emission control Strategies) developed a set of scenarios that are based on the outcomes of the Durban platform negotiations (Kriegler, Tavoni, Aboumahboub, et al., 2014). While one scenario is similar to the RCP2.6 (i.e. the 450 scenario), the two other 2 °C scenario's differ significantly. These two scenarios assume that the Copenhagen pledges are implemented until 2020, after which the 450 ppm target is set[8](Kriegler et al., 2014; McCollum, Nagai, Marangoni, et al., 2013). As these scenarios do not assume idealized climate policy approaches and full technological availability, they are more realistic than the 450 scenario (Krey & Clarke, 2011). The RefPol-450 scenario is selected because it is considered the most realistic 2 °C scenario in the LIMITS study (van der Zwaan, Rösler, Kober, et al., 2014).

The RefPol-450 scenario is the only illustrative scenario with delayed action. The scenario assumes that until 2020 the policies are according to the Copenhagen pledges, and after 2020 the 450 ppmv target is implemented. The scenario is modelled using 7 different models for a comparison study (van der Zwaan et

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[6] Prof. Dr. Detlef van Vuuren, Netherlands Environmental Assessment Agency/Utrecht University; and Dr. Niklas Höhne, Ecofys/Wageningen University.

[7] 2.6 stands for the amount of radiative forcing in W/m^2. Also known as the RCP3PD, where PD stands for peak-and-decline.

[8] One scenario with strengthened policy until 2020, followed by strong climate action (StrPol-450), and a scenario with more lenient policy until 2020, followed by strong climate action (RefPol-450).

al., 2014). This thesis only reviews the RefPol-450 scenario modelled in IMAGE, because IMAGE also is used for the RCP2.6 scenario. As both scenarios are created using the same model, both scenarios are based on the same assumptions. Furthermore, they have the same temporal scale and sectoral resolution.

IEA's 2DS

The International Energy Agency (IEA) created a set of scenarios for their 2012 *Energy Technology Perspectives* (ETP) report (IEA, 2012a). Their 2DS scenario keeps global warming below 2 °C. It is an extensive scenario that shows a resulting emissions pathway that is consistent with the RCP2.6 scenario (Schaeffer & van Vuuren, 2012). Based on their ETP report, the IEA has published several roadmaps for industries or sectors that are consistent with the 2DS and translate the findings of ETP into policies and technology focus areas (IEA, 2012b, 2013a, 2013b, 2013c). In 2014, IEA released an updated version of the ETP report: *ETP2014* (IEA, 2014). This updated version uses a more recent base year and includes recent developments. Therefore, the 2DS from ETP2014 is assessed.

The 2DS scenario is built on the assumption that economic growth is decoupled from demand for energy and materials. This is done by technological developments and behavioural change (e.g. consumption of services substituting consumption of physical goods) (IEA, 2012a, 2014). The scenario is created using the ETP model, which is based on The Integrated MARKAL-EFOM System (TIMES) model (IEA, 2012a, 2014; Loulou, Remne, Kanudia, et al., 2005). Besides TIMES, the IEA also uses stock accounting spreadsheets for detailed modelling of industry (sectors cement, steel, paper, chemicals, and aluminium) and buildings. Furthermore, the IEA's mobility model (MoMo) is used to model transport into more detail (Fulton, Cazzola, & Cuenot, 2009). The model works in five-year time steps and uses 2011 as its base year.

Greenpeace's Energy [R]evolution

In 2005, Greenpeace published their first Energy Revolution scenario for the EU-25 (Greenpeace, 2005). In 2007 they created a similar global scenario, followed by two updates in 2008 and 2010 (Teske, Muth, Sawyer, et al., 2012). In 2012, there was a need to update the 2010 scenario in order to account for major changes in the energy sector (e.g. the nuclear phase-out, the shale gas revolution and oil exploration in the Arctic Circle). Therefore, Greenpeace created the Energy [R]evolution scenario (E[R]) (Teske et al., 2012). This scenario is considered an illustrative scenario by the IPCC in their SRREN report (IPCC, 2012).

E[R] is back-casted from a 2050 target of 4 Gtonne annual CO_2 emission from energy use without the use of nuclear power (Teske et al., 2012). It uses a low amount of biofuels because of some scientific reports that indicate that biofuels might have a higher carbon footprint than fossil fuels (thereby following the precautionary principle). Furthermore, it assumes the use of hydrogen as a fuel in transport. The energy supply is modelled using the Modular Energy System Analysis and Planning environment (MESAP) and Planning Network (PlaNet) using an approach similar as Krewitt et al. (2007). Energy demand projections are based on an analysis of the potential of energy efficiency measures. The E[R] scenario distinguishes the same sectors as the IEA in its *World Energy Outlook* (2012c). Results are given with 5-year intervals until 2050, with base year 2009 (Teske et al., 2012).

WWF & Ecofys' The Energy Scenario

After two years of development, WWF and Ecofys presented The Energy Report in 2011. In this report they assessed whether it is possible to make the transition towards a 100% renewable energy supply. In order to do this, Ecofys created The Energy Scenario (TES) (WWF & Ecofys, 2011). Although 100%

renewable energy is a different target than the 2 °C target, reducing GHG emissions from energy production to zero very likely results in reaching the 2 °C goal[9].

TES is based on ambitious energy saving measures, more recycling and change of behaviour (such as eating less meat). Furthermore, it only uses currently available technologies (therefore, resulting in 95% renewable energy). The scenario is modelled using a combination of energy demand forecasting and energy supply backcasting, giving preference to renewables over bioenergy. The energy demand is forecasted for the sectors industry, transport, buildings & services, and other. The industry sector is divided into sub sectors: iron and steel; non-ferrous metals; non-metallic minerals; paper, pulp and print; chemical and petrochemical; food and tobacco; and other. The emissions are not allocated to the sectors, but brought down to their minimum, only limited by technical feasibility. The results are given from 2000 to 2050 with 5-year steps (WWF & Ecofys, 2011).

Shell's Mountains Scenario

Multinational oil and gas company Shell has been developing scenarios since the 1970s. They use their scenarios to anticipate for disruptive changes. With their most recent scenarios, the New Lens Scenarios, Shell tries to make predictions until 2060 for the first time (Royal Dutch Shell, 2013a). Considering that Shell tries to estimate a most likely future, their scenarios are not focussed on reaching a 2 °C target. However, they do offer a business perspective on the future of energy. The New Lens Scenarios consist of two scenarios: Oceans and Mountains. Because Mountains results in less carbon emissions in 2050 (28 $GtCO_2$ as compared to 40 in the Oceans scenario) only this scenario is discussed.

The Mountains scenario is a socio-economic scenario rather than a technical scenario. Among its assumptions is that there is a large role for policy makers. The transition to low-carbon energy technologies is driven by government interference. This results in the use of CCS, and hydrogen for transport. Furthermore, industry efficiency is driven by internalized externalities. The scenario is modelled using a non-public energy model (Royal Dutch Shell, 2013b). The Mountains scenario provides results for heavy industry, agriculture and other industry, and services sectors. The results are presented until 2060 with 10-year time intervals (Royal Dutch Shell, 2013a).

Carbon Trust's 2050 Scenarios

The mission of the Carbon Trust (a not-for-dividend company) is to accelerate the transition towards a low-carbon economy. In order to assess the consequences of this transition for a number of highly affected sectors, they conducted a study in cooperation with McKinsey & Company. In this study, the Carbon Trust 2050 scenarios were developed; a set of 4 scenarios that have the same 2050 emissions target of 33 $GtCO_2$. Per scenario there are industry specific sub-scenarios. Although these scenarios are not 2 °C scenarios (they have a chance of less than 20% of meeting the 2 °C target), they do offer valuable insight in sector-specific emission reduction potential and future developments (Carbon Trust, 2008).

The 4 macro scenarios differ in the way the 2050 target is achieved: the *carbon markets* scenario introduces carbon pricing as the incentive; the *targeted regulation* scenario uses feed-in tariffs and efficiency standards; the *technology* scenario uses R&D subsidies and regulations; and the *consumption* scenario uses the buying power of consumers to influence companies. The scenarios are modelled by consulting firm

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[9] The climate change effect of TES has not been quantified.

Oxera and the model is not public. The industries that are covered in detail are automotive, aluminium smelting, oil & gas, building insulation, consumer electronics, and beer. Besides that, the energy demand of the manufacturing industry is modelled for 13 sectors. The results are provided in 5-year steps for the years 2000-2050 (Carbon Trust, 2008).

McKinsey's Green World Scenario

In 2006, consulting firm McKinsey & Company collaborated with Swedish utility Vattenfall in order to develop a global marginal abatement cost (MAC) curve. This abatement curve showed the global GHG abatement potential and its costs. In 2009, McKinsey released a report with an updated version of their MAC curve. This time McKinsey used bottom-up modelling to close the emissions gap with technical abatement measures, thus meeting the top-down emission target from IPCC to keep climate warming under 2 °C in their Green World scenario (McKinsey & Company, 2009a).

The McKinsey study does not take behavioural changes into account, and only incorporates abatement measures that are proven to be technically and economically viable, and supported by compelling forces such as policy or industry support. The abatement opportunities are modelled bottom-up for 10 sectors: power, petroleum and gas, cement, iron and steel, chemicals, transport, buildings, forestry, agriculture, and waste. Other industries, sea transport and air transport are estimated top-down. The results are modelled for five-year time intervals from 2005 to 2030 (McKinsey & Company, 2009a).

4.2.2. MCA criteria

The illustrative scenarios show that scenarios differ from each other in many ways. This section assesses these differences. However, the selection criteria used in the MCA differ slightly from the target requirements stated in Table 1 because several target requirements cannot be translated directly into scenario requirements. Other target requirements are not influenced by the scenario selection (e.g. req.6).

First, to ensure verifiability in a complex scenario, the scientific rigor of the scenario is assessed. The scientific method of publishing results and peer-reviewing is an effective way to ensure verifiability. The two indicators used to assess scientific rigor are traceability and source quality. For a scenario to show good traceability, it needs to clearly state the assumptions, approaches and conditions the scenario outcomes are based on. The source quality is assessed by using the percentage of peer-reviewed sources as an indicator. The reasoning behind this is that if an author uses primarily peer-reviewed articles, the emphasis is on source quality. The source quality is considered *good* if more than 50% of the sources is from peer-reviewed scientific journals (for the results from the scenario source quality assessment, see Appendix E).

Second, the scenario needs to be applicable for use in the SITA method. As described in section 2.2.2, the allocation method applied in the scenario is of great importance. Same-costs allocation is considered the best method. Due to differences in temporal scale and sectoral resolution in the illustrative scenarios described above, not every scenario is as useful for the SITA method. Because the scenario's outcomes are used to distil emissions targets, a high sectoral resolution is essential. The sectoral resolution is considered *good* if the scenario provides different outcomes for different industry sectors and different transport sectors. The required time frame is from 2010 to 2050 (req.5 from Table 1). Preferably, the scenario gives year-by-year outcomes in order to incorporate possible curvatures in the pathway (as mentioned in section 2.2.4). In order to meet req.3, the scenario needs to provide sufficient data to construct pathways for all GHGs. If this is not possible, the Kyoto gases will suffice. CO_2 is the best alternative after the Kyoto gases because it represents most of anthropogenic emissions and it is the most studied GHG (IPCC, 2014c). The emission scope is considered *good* if all 3 scopes are assessed for all sectors.

Finally, the illustrative scenarios described above do not all result in an equal likelihood of achieving the 2 °C target. The probability of staying under 2 °C warming should be at least above 60% for a scenario to score good in the MCA.

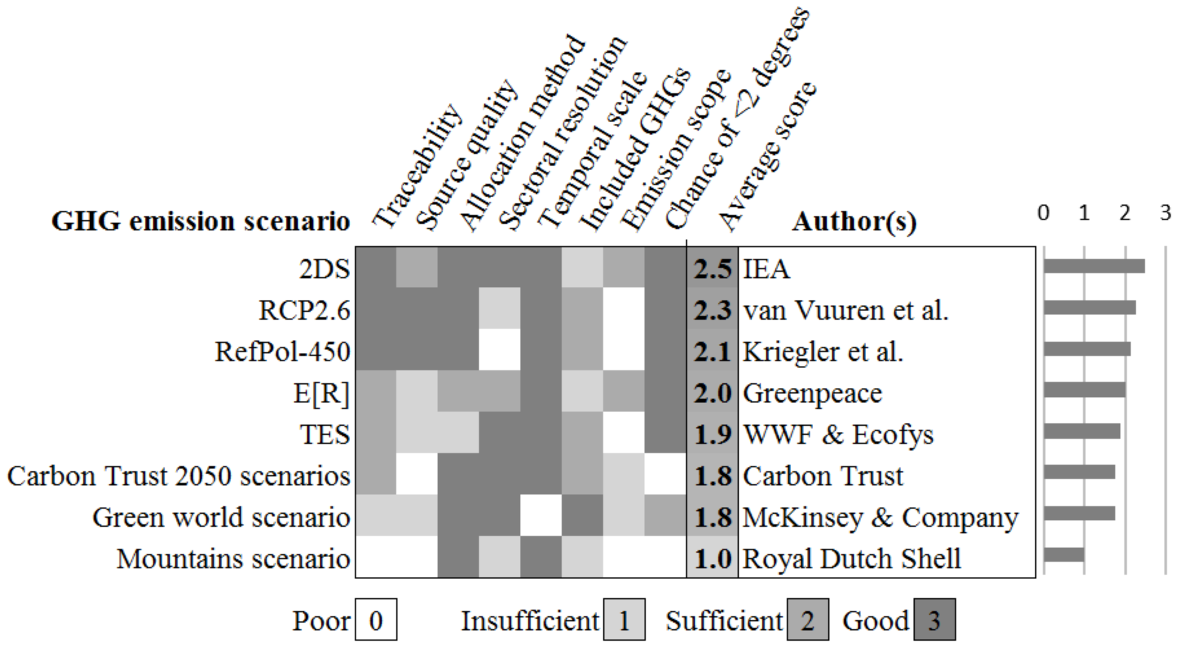
The eight illustrative scenarios are compared using MCA based on these five criteria. The scenarios are scored according to the scenario-rating matrix shown in Table 3. The criteria are considered of equal importance. The scenarios are assessed using their publicly available reports and publicly available supplementary information (thereby meeting req.8 from Table 1).

Table 3: Overview of desired scenario characteristics and how the scenarios are rated on each criterion.

		Good	**Sufficient**	**Insufficient**	**Poor**
Scientific rigor	Traceability	Assumptions, approaches and conditions clearly stated for every part of the scenario	Assumptions, approaches and conditions clearly stated for most parts of the scenario	Assumptions, approaches and conditions not clearly stated for most parts of the scenario	Assumptions, approaches and conditions not clearly stated
	Source quality	More than 50% of sources are peer-reviewed	Between 20% and 50% of sources are peer-reviewed	Less than 20% of sources are peer-reviewed	No sources are peer-reviewed
Scenario applicability	Allocation method	Same-cost principle	Same-reduction principle	Limited only by technical potential	Base-year principle
	Sectoral resolution	Emission and activity outcomes for specific industry sectors and transport sectors	Emission and activity outcomes for a few industry sectors and transport sectors	Emission and activity outcomes only for large aggregated sectors (e.g. Industry and Transport)	No emission or activity outcomes for different sectors
	Temporal scale	5-year outcomes for the range 2010-2050	Outcomes for the year 2050	Outcomes for a year after 2030	No outcomes after 2030
	GHGs	All GHGs	All Kyoto gases	CO_2	Only non-CO_2 Kyoto gases
	Emission scope	All 3 scopes for all sectors	Scopes 1 and 2 for all sectors and scope 3 for some sectors	Scopes 1 and 2	Scope 1
Scenario target	Probability of staying under 2 degrees	Higher than 60%	Between 50% and 60%	Between 40% and 50%	Under 40%

4.2.3. MCA results

The results of the MCA are shown in Figure 11. The scenarios are ranked according to their average score on the eight criteria above. The Mountains scenario from Shell is ranked the lowest. This is because the assumptions and approach are not clearly stated, the 2 °C target not achieved, and the scientific rigor low. The Green World scenario is also not suitable for this thesis, because of its 2030 temporal scale and its lack of a scientific basis. The Carbon Trust's 2050 scenarios give some very specific information on the right time scale, but lack traceability and specific emission data, and are not built on scientific consensus. RefPol-450, TES, and the E[R] scenario have the same average score. RefPol-450 scores poor on sectoral detail and emissions detail, and E[R] loses points on traceability and scientific rigor. TES scores less because it mainly focusses on energy modelling as opposed to emissions modelling, and because it does not use an allocation method. RCP2.6 scores relatively high, but lacks data from scope 2 and 3. The 2DS scenario is suited best for use in the SITA methodology. 2DS scores *good* on five criteria, like RCP2.6, but scores slightly better on the other 3. The source quality of 2DS is not optimal. However, as can be seen in Appendix E, the ETP report contained the highest absolute amount of peer-reviewed sources. The main weakness of the 2DS scenario is that it only targets CO_2. This means that if 2DS is used, requirement 3 cannot be met. However, because of its advantages (especially in detailed sectoral emission information), it is selected as the backbone of the emissions target-setting methodology in this thesis.



GHG emission scenario	Traceability	Source quality	Allocation method	Sectoral resolution	Temporal scale	Included GHGs	Emission scope	Chance of <2 degrees	Average score	Author(s)
2DS	3	2	3	3	3	1	2	3	2.5	IEA
RCP2.6	3	3	3	1	3	2	0	3	2.3	van Vuuren et al.
RefPol-450	3	3	3	0	3	2	0	3	2.1	Kriegler et al.
E[R]	2	1	2	2	3	1	2	3	2.0	Greenpeace
TES	2	1	1	3	3	2	0	3	1.9	WWF & Ecofys
Carbon Trust 2050 scenarios	2	0	3	3	3	2	1	0	1.8	Carbon Trust
Green world scenario	1	1	3	3	0	3	1	2	1.8	McKinsey & Company
Mountains scenario	0	0	3	1	3	1	0	0	1.0	Royal Dutch Shell

Poor 0 Insufficient 1 Sufficient 2 Good 3

Figure 11: Results from the scenario selection multi-criteria analysis.

It is important to state that the scenario choice has a high influence on the outcome of the target-setting methodology and that this selection is merely for the purpose of illustration and to analyse the workings of the SITA method. This means that improved scenarios could enable improved SITA targets. In order to determine the impact of selecting the 2DS as the basis of the methodology, the 2DS scenario is compared to other scenarios. For this comparison, the scenarios with an average score of at least 2 out of 3 are used; RCP2.6, TES, RefPol-450, and E[R]. Although it would be best to compare emission pathways for specific sectors for each scenario, this is not possible because RCP2.6 and RefPol-450 lack the sectoral detail. However, the supply side of the scenarios can be compared with relative ease. Furthermore, the upstream emissions from energy supply greatly determine the emissions in the demand sectors (IPCC, 2014c). The different mix of primary energy sources can determine the outcomes for a single sector. Therefore, the primary energy use for each scenario is compared per energy source. Because *The Energy Report* only provided final energy use, the primary energy use is estimated using the primary/final energy ratio for 2050 from 2DS. Note that this estimation is for illustrative purposes only. The conversion efficiency can differ significantly between scenarios.

In Figure 12, the total primary energy use in the illustrative scenarios is compared on the left and shares of individual energy sources are compared on the right. The error bars show the 50% range. As can be seen in Figure 12, the total primary energy consumption of 2DS in 2050 is higher than every other scenario except for RCP2.6. Furthermore, a clear distinction is visible between TES and E[R], and the rest. First, the two scientific scenarios and 2DS show a higher primary energy use than the others. Second, they show a significantly higher share of fossil fuels in the energy mix. For TES, this can be explained by the different scenario target: 95 % renewable. For the E[R] scenario, the difference can be explained by its demand side modelling (which assumes implementing all technically feasible abatement measures).

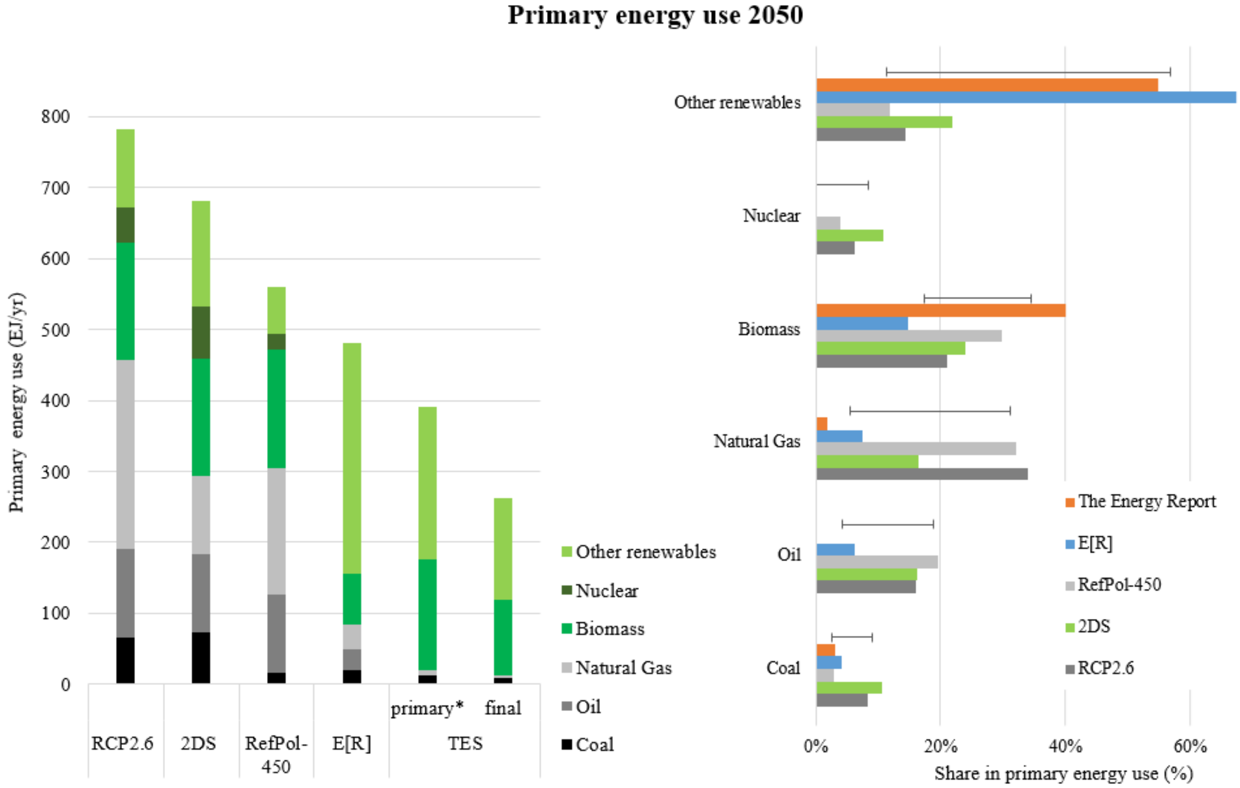


Figure 12: Comparison of RCP2.6, 2DS, RefPol-450, Energy [R]evolution, and The Energy Scenario's 2050 primary energy mix (IEA, 2012a; Teske et al., 2012; van der Zwaan et al., 2014; van Vuuren, Stehfest, et al., 2011; WWF & Ecofys, 2011)

The shares of different energy sources differ significantly among scenarios. For oil, coal and biomass the shares in the energy mix are fairly similar. The largest spread is seen in the renewables and natural gas shares. TES and E[R] differ in their share of nuclear, because of the choice to not consider nuclear an option for 2050. Note that in RCP2.6, 2DS, and RefPol-450 carbon capture and storage (CCS) plays a significant part, resulting in far less emissions from burning fossil fuels and biomass than Figure 12 implies.

This brief analysis shows that the outcomes of the 2DS scenario are not extreme compared to the others. Although the shares of nuclear and coal are outside the 50% range, the 2DS can be considered representative for the selection of scenarios. However, considering that this comparison is only on primary energy use, and not on mitigation options and allocation across sectors, this comparison is not adequate to assess scenario similarity. However, it does show that the assumptions that are used as the foundation of the scenarios are similar and the energy system outcomes are in the same order of magnitude. In addition to these conclusions, the in section 4.2.1 mentioned experts agreed on the selection of the 2DS scenario for this purpose. Therefore, 2DS is used in this thesis.

4.3. Sectors, scopes and intensity indicators

After selecting the 2DS as the input scenario for the SITA method, this section determines for what sectors 2DS provides sufficient information to calculate GHG intensity pathways. Next, the included sectors and sector boundaries are defined. Finally, appropriate activity indicators for the sectors are defined and intensity indicators are assigned to the sectors.

4.3.1. Sectors and scopes

In determining what sectors to include in the SITA method, the chosen scenario is critical. If the scenario does not present the required data for a sector, it cannot be included. ETP2014 distinguishes four aggregated sectors: energy conversion, industry, transport, and buildings. In the aggregated energy conversion sector, only sufficient CO_2 emissions and activity data is available to construct an intensity pathway for the power generation sector. For the other energy conversion sectors (e.g. refineries, synfuel plants, or heat generation), insufficient data is available. Therefore, they are left outside the SITA scope from hereon.

The aggregated industry sector describes the cement, iron and steel, pulp and paper, aluminium, and chemicals and petrochemicals sectors in detail and aggregates the other industry sectors into one sub-sector. For all the industry sectors, sufficient CO_2 emissions and activity data is available to construct intensity pathways. Therefore, all six industry sectors are covered in the SITA method.

The aggregated transport sector covers five transport modes: air, light road, heavy road, rail, and shipping. These transport modes are subdivided into passenger and freight transport. For all these modes, the well-to-wheel (WTW) emissions in 2DS are available. However, the WTW CO_2 emissions also include refining of fuels. Because fuel refining is not a transport activity, the WTW data is not considered to be ideal. Therefore, tank-to-wheel (TTW) data is requested from IEA. TTW emissions only cover the emissions that result from the transport activity. Although this data is currently not publicly available (making it difficult to verify), this data will become publicly available in the near future (Fernandez, 2014). The TTW data only covers passenger transport, so freight transport is left outside of the SITA scope. Furthermore, activity data is not provided for all these transport modes. For shipping, no activity data is given, and therefore shipping is not included.

The CO_2 intensity pathways from the included passenger transport sectors are focusing on the entire vehicle fleet's CO_2 emissions. With a relatively simple calculation, these pathways can be translated to intensity pathways for new vehicles. However, to do this, the average lifetime of the vehicles is necessary.

Note that the emissions from light road passenger transport are mostly attributed to consumers instead of companies. As this methodology is for companies, the intensity pathway of the light road passenger transport sector is recalculated into the scope 3 target for automobile manufacturers. This recalculation step is necessary because the target for new cars should be below the fleet average. Therefore, an automobile manufacturer has a scope 1 and 2 target according to the other industry sector, and a scope 3 target according to the light road passenger vehicle sector. For other passenger transport sectors, the buying decision is often made by companies (e.g. a public transport company that buys buses for its fleet). For these sectors, the intensity pathways are corporate scope 1 targets. Converting the other transport pathways is possible, but because the average lifetime of other transport modes were not found, they are excluded.

The aggregated buildings sector consists of the residential and commercial buildings sub-sectors. Because SITA targets companies, only the service buildings sub-sector is included in the scope.

All included sectors are shown in Table 4. In order to define the included sectors, the Global Industry Classification Standard (GICS) classification is used. What sector includes what GICS sectors is stated in Appendix D.

Table 4: SITA sectors, intensity indicators, and included scopes.

#	Sector	Intensity indicator	Included Scopes
1	Power generation	gCO2/kWh	Scope 1
2	Cement	tCO2/t cement	Scopes 1&2
3	Iron and steel	tCO2/t crude steel	Scopes 1&2
4	Pulp and paper	tCO2/t paper and cardboard	Scopes 1&2
5	Aluminium	tCO2/t aluminium	Scopes 1&2
6	Chemicals and petrochemicals	%2011 gCO2/VA	Scopes 1&2
7	Other industry	%2011 gCO2/VA	Scopes 1&2
8	Aviation passenger transport	gCO2/pkm	Scopes 1&2
9	Light road passenger transport	gCO2/pkm	Scopes 1&2
10	Heavy road passenger transport	gCO2/pkm	Scopes 1&2
11	Rail passenger transport	gCO2/pkm	Scopes 1&2
12	Service buildings	kgCO2/m2/year	Scopes 1&2
13	Light road passenger vehicles	gCO2/pkm	Scope 3

4.3.2. Intensity indicators

Table 4 displays the CO_2 intensity indicators for the thirteen included sectors. For the ***power generation*** sector, the amount of electricity generated (in kWh) is used as the activity indicator, because it is directly available in 2DS (IEA, 2014). The amount of kWh is a common indicator for activity in the power generation sector (Eggink, 2013). The intensity indicator is the amount of CO_2 emissions (in g) per power generated (in kWh).

The ***cement, iron & steel, pulp & paper,*** and ***aluminium*** sectors are homogeneous sectors (Farla, 2000; Phylipsen et al., 1998). Because activity projections should be in line with the scenario, the same activity indicators are used as presented in ETP2014 (IEA, 2014). Therefore, the amount of cement, crude steel, paper and cardboard (excluding recovered paper), and aluminium (primary and secondary) produced are used as the activity indicators for these sectors, respectively. The activity in the iron and steel sector is based on crude steel production because of simplicity, but in reality, a lot of different iron and steel products and intermediate products can be distinguished (Farla, 2000). This also holds for the cement, pulp and paper, and aluminium sectors to some degree (Phylipsen et al., 1998). However, 2DS does not show any projections of intermediate products nor the emissions attributed to the production of those products. The intensity indicator for these sectors is the amount of CO_2 (in tonne) per amount of final product (in tonne).

Because the sectors ***chemicals and petrochemicals, and other industry*** are heterogeneous, using a physical activity indicator is not possible. Therefore, the amount of VA is used as the activity indicator. Because sectoral VA is unknown, it is assumed to grow proportionally to global GDP. By assuming this, an intensity change pathway can be constructed (in % change compared to 2011). This % change is later applied to the company's VA in base year 2011.

In the four ***passenger transport*** sectors, the indicator that best describes the actual activity in the sector is the amount of passenger kilometre (Eggink, 2013). This unit is calculated by multiplying the distance traveled with the passengers transported. The intensity indicator used for the four passenger transport sectors is the amount of CO_2 emitted (in g) per distance travelled or cargo transported (in pkm).

For ***service buildings***, the indicator for activity is square meter, like used in Girod & De Haan (2010) and Girod, van Vuuren, & Hertwich (2014). The intensity indicator for commercial buildings is the amount of CO_2 emissions (in kg) per surface area (in m^2) per year.

4.4. Calculating sectoral intensity pathways

This section describes the calculation steps to turn the data from 2DS into the sectoral intensity pathways required for the SITA method.

For all sectors that use physical activity indicators (i.e. power generation, cement, iron and steel, pulp and paper, aluminium, air passenger transport, light road passenger transport, heavy road passenger transport, rail passenger transport, and service buildings) the calculation of the scope 1 carbon intensity is quite simple. The sectoral CO_2 emissions are divided by the sectoral activity. For simplicity, linear interpolation is used to fill data gaps (the interpolated values are printed in italics in Table 5 and Table 6).

For the sectors chemicals and petrochemicals, and other industry a slightly different method is used. Since the sectoral VA growth is not given, their VA is assumed to grow proportionally to global GDP (which is given in ETP2014). By normalizing the change in intensity, the pathway is constructed without knowing the total sectoral VA in the base year.

Because ETP2014 also projects electricity use for all sectors but the power generation sector, scope 2 CO_2 emission targets can be constructed for these sectors (although this targets only emissions from electricity generation, the amount of heat, steam, and cooling is assumed to be negligible). This is done by first dividing the total sector electricity use by the sector activity to get the electricity intensity (in kWh/activity). This electricity intensity is then multiplied with the carbon intensity of global electricity in that year (which is calculated; the power generation scope 1 intensity pathway) to get the emissions from generating that electricity (in CO_2 /activity).

The intensity pathway for light road passenger vehicles (not to be confused with light road passenger transport) is not calculated from 2DS data directly, but derived from the light road passenger transport intensity pathway. The recalculation is required because targets for manufacturers are for new vehicles, and those for transport companies are for the current fleet. In essence, the pathway for new vehicles is created by shifting the fleet pathway to the left by half the average vehicle lifetime (as shown in Figure 13). An average lifetime of 15 years is used (like that used by IPCC (2014b)). The implicit assumption made is that the new cars now are the average cars in 7.5 years. This method neglects growth of the total car fleet for simplicity.

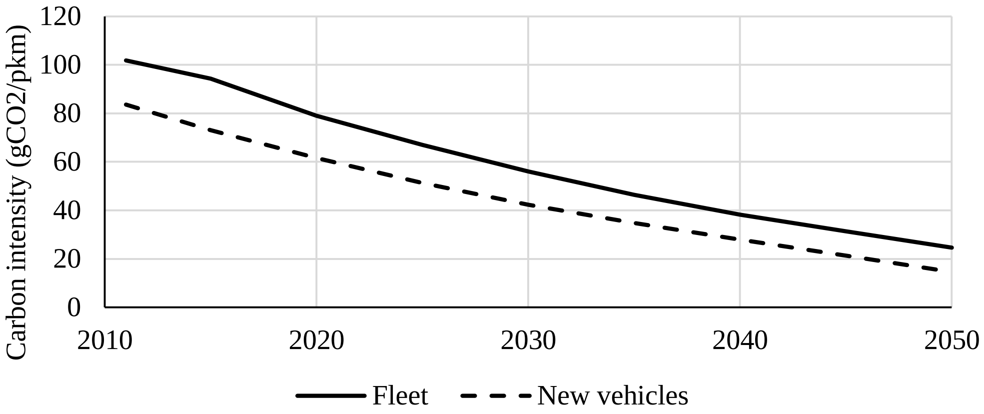


Figure 13: Deriving the new light road passenger vehicles intensity pathway from the light road passenger transport fleet pathway.

4.5. Sector data

Table 5, and Table 7 show the data that is retrieved from ETP2014. The (linearly) interpolated values are printed in italics.

Table 5: CO2 emissions per sector in 2DS (IEA, 2014).

#	**Sector**	**Unit**	**2010**	**2011**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
1	Power generation	MtCO2		13,068	*12,733*	12,314	10,807	8,316	5,417	2,859	1,614	1,151
2	Cement	MtCO2		2,163	*2,338*	2,558	2,540	2,333	2,212	2,059	1,884	1,692
3	Iron and steel	MtCO2		2,991	*3,135*	3,315	3,136	2,912	2,683	2,473	2,253	2,044
4	Pulp and paper	MtCO2		237	*234*	231	221	209	196	184	172	164
5	Aluminium	MtCO2		150	*187*	232	258	285	303	315	325	333
6	Chemicals and petrochemicals	MtCO2		1,273	*1,626*	2,067	2,094	2,038	2,020	2,011	2,000	1,987
7	Other industry	MtCO2		2,084	*1,858*	1,576	1,360	1,103	954	959	936	903
8	Aviation passenger transport	MtCO2	755	*764*	797	821	868	913	925	948	983	1,020
9	Light road passenger transport	MtCO2	2,895	*2,936*	3,102	3,000	2,774	2,410	2,105	1,813	1,534	1,230
10	Heavy road passenger transport	MtCO2	356	*354*	343	393	393	382	377	358	336	315
11	Rail passenger transport	MtCO2	19	*19*	19	32	34	37	40	36	30	23
12	Service buildings	MtCO2		876	*902*	934	882	811	778	739	694	645

Table 6: Activity per sector in 2DS (IEA, 2014).

#	Sector	Activity indicator	2010	2011	2015	2020	2025	2030	2035	2040	2045	2050
1	Power generation	TWh		22,130	*24,615*	27,721	30,315	32,713	34,542	36,295	38,071	40,161
2	Cement	Mtonne cement		3,635	*3,972*	4,394	4,506	4,359	4,441	4,476	4,489	4,475
3	Iron and steel	Mtonne crude steel		1,518	*1,661*	1,840	1,934	2,023	2,106	2,179	2,239	2,295
4	Pulp and paper	Mtonne paper and cardboard		403	*445*	499	556	603	649	691	729	758
5	Aluminium	Mtonne aluminium		93	*116*	144	163	186	202	214	224	234
6	Chemicals and petrochemicals	GDP%		100%	117%	142%	168%	199%	227%	260%	297%	339%
7	Other industry	GDP%		100%	117%	142%	168%	199%	227%	260%	297%	339%
8	Aviation passenger transport	Billion pkm		4,332	*4634*	5,012	5,530	5,968	6,280	6,686	7,201	7,765
9	Light road passenger transport	Billion pkm		28,842	*32,908*	37,992	41,393	43,032	45,351	47,480	48,981	49,930
10	Heavy road passenger transport	Billion pkm		7,702	*9,654*	12,093	13,576	14,659	15,903	16,879	17,680	18,454
11	Rail passenger transport	Billion pkm		2,802	*3,664*	4,525	5,290	6,253	7,371	8,114	8,726	9,235
12	Service buildings	Million m2 floor area	37,633	*38,261*	*40,771*	43,908	*48,016*	52,124	*54,787*	57,449	*59,982*	62,514

Table 7: Electricity use per sector in 2DS (IEA, 2014).

#	Sector	Unit	2011	2015	2020	2025	2030	2035	2040	2045	2050
1	Power generation	TWh									
2	Cement	TWh	358	*389*	428	436	425	436	444	453	458
3	Iron and steel	TWh	1,094	*1,256*	1,458	1,533	1,619	1,719	1,831	1,936	2,036
4	Pulp and paper	TWh	506	*530*	561	600	628	656	678	697	711
5	Aluminium	TWh	678	*816*	989	1,078	1,175	1,228	1,264	1,283	1,289
6	Chemicals and petrochemicals	TWh	1,164	*1,386*	1,664	1,783	1,861	1,792	1,747	1,708	1,664
7	Other industry	TWh	4,167	*4,660*	5,278	5,833	6,111	6,667	6,667	6,667	6,667
8	Aviation passenger transport	TWh	0	*0*	0	0	0	0	0	0	0
9	Light road passenger transport	TWh	25	*26*	28	58	153	350	656	1,025	1,364
10	Heavy road passenger transport	TWh	0	*0*	0	0	0	0	0	0	0
11	Rail passenger transport	TWh	67	*67*	67	89	106	128	156	178	200
12	Service buildings	TWh	4,242	*4,626*	5,106	5,417	5,728	5,728	6,014	6,014	6,292

4.6. Sectoral targets

Table 8 shows the intensity pathways for the base year 2011 and for 5-year intervals from 2015 to 2050. The pathways are calculated from the data shown in section 4.5 in the way described in section 4.4.

Table 8: Sectoral CO2 intensity pathways distilled from 2DS (IEA, 2014).

#	Sector	Unit	Scope	2011	2015	2020	2025	2030	2035	2040	2045	2050
1	Power generation	gCO2/kWh	1	590.51	517.29	444.22	356.49	254.20	156.82	78.77	42.40	28.65
2	Cement	tCO2/t cement	1	0.60	0.59	0.58	0.56	0.54	0.50	0.46	0.42	0.38
			2	0.06	0.05	0.04	0.03	0.02	0.02	0.01	0.00	0.00
3	Iron and steel	tCO2/t crude steel	1	1.97	1.89	1.80	1.62	1.44	1.27	1.14	1.01	0.89
			2	0.43	0.39	0.35	0.28	0.20	0.13	0.07	0.04	0.03
4	Pulp and paper	tCO2/t paper and cardboard	1	0.59	0.53	0.46	0.40	0.35	0.30	0.27	0.24	0.22
			2	0.74	0.62	0.50	0.38	0.26	0.16	0.08	0.04	0.03
5	Aluminium	tCO2/t aluminium	1	1.61	1.61	1.61	1.58	1.54	1.50	1.47	1.45	1.42
			2	4.30	3.65	3.05	2.36	1.61	0.96	0.46	0.24	0.16
6	Chemicals and petrochemicals	2011%	1	100%	109%	114%	98%	81%	70%	61%	53%	46%
			2	100%	89%	76%	55%	35%	18%	8%	4%	2%
7	Other industry	2011%	1	100%	76%	53%	39%	27%	20%	18%	15%	13%
			2	100%	84%	67%	50%	32%	19%	8%	4%	2%
8	Aviation passenger transport	gCO2/pkm	1	176.32	172.05	163.74	157.02	152.92	147.28	141.81	136.51	131.34
			2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	Light road passenger transport	gCO2/pkm	1	101.80	94.27	78.97	67.03	56.00	46.42	38.19	31.32	24.63
			2	0.51	0.41	0.32	0.50	0.90	1.21	1.09	0.89	0.78
10	Heavy road passenger transport	gCO2/pkm	1	45.92	35.51	32.53	28.93	26.03	23.73	21.20	18.99	17.07
			2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	Rail passenger transport	gCO2/pkm	1	6.70	5.23	7.08	6.42	5.91	5.39	4.45	3.47	2.45
			2	14.05	9.41	6.55	5.99	4.29	2.72	1.51	0.86	0.62
12	Service buildings	kgCO2/m2/year	1	22.91	22.12	21.26	18.37	15.56	14.19	12.86	11.58	10.32
			2	65.47	58.69	51.65	40.22	27.93	16.39	8.25	4.25	2.88
13	Light road passenger vehicles	gCO2/pkm	3	83.56	73.00	61.51	51.21	42.31	34.76	27.97	21.28	14.59

4.7. Sectoral target feasibility assessment

In this section, the results of the sectoral study are checked for feasibility. Per sector, the intensity pathway is critically assessed and compared to best available technologies.

4.7.1. Power generation

The carbon intensity of electricity is required to decrease from 591 gCO_2/kWh in 2011 to 29 gCO_2/kWh in 2050 in order to limit global warming to 2 °C. Considering that plenty of renewable energy technologies are available that have no scope 1 emissions (e.g. geothermal, hydropower, nuclear, etc.), this target is feasible (IPCC, 2014c). Furthermore, Ecofys (2011) calculated that a 95% renewable energy supply is possible and McKinsey (2009b) estimated that a low-carbon power generation sector is technologically feasible at acceptable cost.

4.7.2. Cement

The scope 1 carbon intensity of cement is required to decrease from 0.6 tCO_2/tonne cement in 2011 to 0.4 tCO_2/tonne cement in 2050 in order to limit global warming to 2 °C. Scope 2 carbon intensity needs to decrease from 58 $kgCO_2$/tonne cement in 2011 to 3 $kgCO_2$/tonne cement in 2050. Worrell, Price, Martin, Hendriks, and Meida (2001) estimated that energy efficiency improvements and use of blended cement could reduce CO_2 emissions with about 40% and 22%, respectively. A recent study found that specific energy reduction in the cement sector can be reduced by 27% (Kermeli, Graus, & Worrell, 2014). Furthermore, CO_2 emissions from cement production can be captured and stored (Worrell et al., 2001). Therefore, the required scope 1 CO_2 emission reduction of 36% is considered feasible. Since scope 2 emissions are required to decrease by the same percentage as the power generation sector (95%), this target is also feasible.

4.7.3. Iron and steel

The scope 1 carbon intensity of crude steel is required to decrease from 2 tCO_2/tonne crude steel in 2011 to 0.9 tCO_2/tonne crude steel in 2050 in order to limit global warming to 2 °C. Scope 2 carbon intensity needs to decrease from 426 $kgCO_2$/tonne crude steel in 2011 to 25 $kgCO_2$/tonne crude steel in 2050. The specific energy consumption for iron and steel production can be reduced by 31% by implementing energy efficiency measures (Kermeli et al., 2014; Worrell, Blinde, Neelis, et al., 2010). Fuel switching and increased recycling can further decrease the carbon intensity (IPCC, 2014c). Combining these measures with CCS makes the proposed 55% intensity reduction feasible (IPCC, 2014c). The scope 2 intensity reduction is below the power generation sector reduction, so it allows for increasing electricity consumption. Therefore, the scope 2 target is considered feasible.

4.7.4. Pulp and paper

The scope 1 carbon intensity of paper and paperboard (excluding recovered paper) is required to decrease from 0.6 tCO_2/tonne paper and paperboard in 2011 to 0.2 tCO_2/tonne paper and paperboard in 2050 in order to limit global warming to 2 °C. Scope 2 carbon intensity needs to decrease from 616 $kgCO_2$/tonne paper and paperboard in 2011 to 27 $kgCO_2$/tonne paper and paperboard in 2050. According to Kermeli et al. (2014), an average energy savings potential of 30% is possible for the pulp and paper sector. Combining this with the use of biomass or waste as a fuel, makes the scope 1 target of 64% reduction feasible. The scope 2 target is more stringent than that of the power generation sector (96% reduction as opposed to 95% reduction). This could be the result of implementation of combined heat and power production (IPCC, 2014c).

4.7.5. Aluminium

The scope 1 carbon intensity of (primary and secondary) aluminium is required to decrease from 1.6 tCO_2/tonne aluminium in 2011 to 1.4 tCO_2/tonne aluminium in 2050 in order to limit global warming to 2 °C. Scope 2 carbon intensity needs to decrease from 4.3 tCO_2/tonne aluminium in 2011 to 0.2

tCO_2/tonne aluminium in 2050. Scope 1 emissions from aluminium manufacturing can be reduced by 22% (Kermeli et al., 2014). Therefore, the required 12% reduction is feasible. The aluminium sector needs to reduce its scope 2 emissions by 96%, so reduction of electricity use is necessary. This is possible by increasing the share of recycled aluminium (IPCC, 2014c)

4.7.6. Chemicals and petrochemicals

The scope 1 carbon intensity of VA in the chemicals and petrochemicals sector is required to decrease to 46% of 2011 intensity in 2050 in order to limit global warming to 2 °C. Scope 2 carbon intensity needs to decrease to 2% of 2011 intensity in 2050. Implementing best-practice technology in the chemicals and petrochemicals sector can achieve fuel savings of 37% (Kermeli et al., 2014). Because scope 1 emissions in this sector are primarily due to fossil fuels, this means the emission reduction is about the same percentage. The remaining intensity reduction can be explained by decoupling of GDP and production. For scope 2 emissions, the target can be achieved by electricity savings (25% reduction (Kermeli et al., 2014)), decarbonisation of the power generation sector (95% reduction) and the remaining part is due to the decoupling of GDP and production growth.

4.7.7. Other industry

The scope 1 carbon intensity of VA in the other industry sector is required to decrease to 13% of 2011 intensity in 2050 in order to limit global warming to 2 °C. Scope 2 carbon intensity needs to decrease to 2% of 2011 intensity in 2050. The other industry sector is dominated by small- and medium-sized enterprises (SMEs). As these SMEs typically have larger potential than the large energy-intensive companies, the targets are achievable by implementing generic efficiency improvements (such as more efficient motor systems) and decarbonizing electricity (Saygin, Patel, & Gielen, 2010). Also for this sector, accounting for decoupling of GDP growth and activity growth is necessary.

4.7.8. Aviation passenger transport

The scope 1 carbon intensity of aviation passenger transport is required to decrease from 176 gCO_2/pkm in 2011 to 131 gCO_2/pkm in 2050 in order to limit global warming to 2 °C. The aviation passenger transport sector has no scope 2 emissions in 2011, and needs to avoid scope 2 carbon emissions until 2050. Fuel efficiency gains of 40-50% are possible for aircrafts (IPCC, 2014c). Therefore, the 26% intensity reduction is considered feasible.

4.7.9. Light road passenger transport/Light road passenger vehicles

The scope 1 carbon intensity of light road passenger transport is required to decrease from 102 gCO_2/pkm in 2011 to 25 gCO_2/pkm in 2050 in order to limit global warming to 2 °C. Scope 2 carbon intensity is allowed to increase from 0.5 gCO_2/pkm in 2011 to 0.8 gCO_2/pkm in 2050. Light road passenger transport fuel consumption can be reduced by drive-train redesigns (25% reduction), hybrid designs (35% reduction) and other non-drive-train changes (25% reduction) (IPCC, 2014c). Battery electric vehicles can further increase energy efficiency and reduce CO_2 emissions, making the 76% intensity reduction feasible (IEA, 2012b; IPCC, 2014c). The scope 2 emissions from light road passenger vehicles are allowed to increase with 53%. This is due to electric vehicles, which have no scope 1 CO_2 emissions.

4.7.10. Heavy road passenger transport

The scope 1 carbon intensity of heavy road passenger transport is required to decrease from 46 gCO_2/pkm in 2011 to 17 gCO_2/pkm in 2050 in order to limit global warming to 2 °C. The heavy road passenger transport sector has no scope 2 emissions in 2011, and needs to avoid scope 2 carbon emissions until 2050. For heavy road passenger transport three emission reduction options are identified: hybrid drive trains (25% reduction), reducing aerodynamic drag (10% reduction), and increasing carrying capacity (up to 32% reduction) (IPCC, 2014c). Less carbon-intensive fuels and use of fuel cell technology can reduce the emissions intensity further (IPCC, 2014c). Therefore, the scope 1 target of 63% reduction is considered feasible.

4.7.11. Rail passenger transport

The scope 1 carbon intensity of rail passenger transport is required to decrease from 7 gCO_2/pkm in 2011 to 3 gCO_2/pkm in 2050 in order to limit global warming to 2 °C. Scope 2 carbon intensity needs to decrease from 14 gCO_2/pkm in 2011 to 0.6 gCO_2/pkm in 2050. Rail scope 1 CO_2 emission intensity can effectively be reduced by using electricity powered trains instead of fossil fuel powered trains. Decarbonisation of electricity and energy efficiency measures (like regenerative braking) can further decrease CO_2 emissions (IPCC, 2014c). However, rail transport is already very energy-efficient. Therefore, the scope 1 and 2 targets (63% and 96% reduction, respectively) are considered optimistic, but feasible.

4.7.12. Service buildings

The scope 1 carbon intensity of service buildings is required to decrease from 23 $kgCO_2/m^2$/year in 2011 to 10 $kgCO_2/m^2$/year in 2050 in order to limit global warming to 2 °C. Scope 2 carbon intensity needs to decrease from 65 $kgCO_2/m^2$/year in 2011 to 3 $kgCO_2/m^2$/year in 2050. Heating and cooling has the largest contribution to GHG emissions (Girod et al., 2014). Final energy use for heating and cooling can be reduced by up to 90% (IIASA, 2012). Therefore, the 55% scope 1 CO_2 reduction is considered feasible. The scope 2 target is more stringent than that of the power generation sector. Therefore, additional electricity savings are necessary. However, electricity savings are expected to be around 50% in 2050 for all appliances (IIASA, 2012).

4.8. Sectoral intensity targets conclusion

The 2DS scenario as presented in the ETP2014 report is used as the basis of the sectoral intensity targets (IEA, 2014). Based on available scenario data, twelve sectors are selected for which individual intensity pathways are constructed. Furthermore, one intensity pathway is recalculated into another sector's scope 3 emission pathway. The 2050 targets for all sectors are found to be technically feasible.

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5. Case studies

To test the SITA methodology on a company level, case studies are conducted. Three illustrative sectors are selected. Of each sector, two illustrative companies are selected as a case study:

- The power generation sector is selected because this sector emits more CO_2 than any other single sector (about 12 $GtCO_2eq$ in 2010) and is expected to do so in the future (IPCC, 2014c). The power generation sector is expected to see the most radical change in the future when it comes to GHG emission reductions (IEA, 2013c; McKinsey & Company, 2009a; WWF & Ecofys, 2011). Two illustrative companies in the power generation sector are selected: Électricité de France (EDF) and the China Light and Power Group (CLP). These companies differ in size, geographical location, and mix of generation technologies.
- The iron and steel sector is selected because it has high direct and indirect CO_2 emissions. In 2010, the sector emitted around 2.5 $GtCO_2$ (IEA, 2012a). Furthermore, it is an example of a highly homogeneous sector. Research has shown that the most emission reduction potential for steel companies is in China (IPCC, 2014a). Therefore, it would be interesting to perform a case study on a Chinese steel company. However, no Chinese steel company was found that publishes its CO_2 emissions. Therefore, the following two illustrative iron and steel companies are selected: ArcelorMittal and POSCO. These companies differ in size and geographical location.
- The automotive manufacturing sector is selected because of its large share of product use CO_2 emissions in total CO_2 emissions (Carbon Trust, 2011; Renault, 2011). A lot of CO_2 emission reduction potential is available in the automotive sector (McKinsey & Company, 2009b). Comparing companies in different continents would allow for analysis of differences between companies. However, only European companies were found that report VA. Two illustrative automotive companies are selected: Daimler, and Volkswagen.

Data for the case studies is collected from publicly available sources in order to meet the verifiability requirement from Table 1. The CO_2 emissions data is collected from publicly available CDP reports and the activity data from the companies' annual reports or sustainability reports.

After the company intensity pathways are calculated, the feasibility of these pathways is tested. To do this, the annual intensity growth (or reduction) rate is calculated. Since data is not available for every year, the compound average annual growth rate (CAGR) is calculated for time intervals. The CAGR is the annual year-on-year growth or reduction that results in the total growth or reduction over the time interval. The CAGR is calculated as described in Appendix C. Section 5.1 shows the input parameters used to calculate the intensity targets. The results of the case studies are presented per sector in sections 5.2 to 5.4.

5.1. Company input data

Table 9 shows the company data that is retrieved from CDP reports and annual reports. An overview of the sources from which the data originates is provided in Appendix F.

Table 9: Company inputs for case studies.

Sector	Company	Input	2010	2011	2012	2013
Power Generation	EDF	Scope 1 CO_2 emissions[10]	80,576	70,936	80,284	
		Activity (TWh)	630	628	643	
	CLP	Scope 1 CO_2 emissions[10]	41,649	44,260	38,245	
		Activity (TWh)	55	49	50	50
Iron and steel	ArcelorMittal	Scope 1 CO_2 emissions[10]	165,226	162,028	158,192	
		Scope 2 CO_2 emissions[10]	19,599	17,902	17,256	
		Activity (kt crude steel)	90,600	91,891	88,200	91,200
	POSCO	Scope 1 CO_2 emissions[10]	68,705	74,602	73,525	
		Scope 2 CO_2 emissions[10]	2,974	3,625	3,471	
		Activity (kt crude steel)	33,716	37,325		
Automotive	Daimler	Scope 1 CO_2 emissions[10]	1,064	1,016	960	
		Scope 2 CO_2 emissions[10]	2,635	2,503	2,331	
		Activity (M€$_{2010}$VA)	2,773	3,641	4,094	5,528
		Vehicle CO2 intensity (gCO_2/vkm)[11]	158	150	140	134
	Volkswagen	Scope 1 CO_2 emissions[10]	1,287		4,134	
		Scope 2 CO_2 emissions[10]	6,307		4,572	
		Activity (M€$_{2010}$VA)	32,922	46,625	56,804	44,998
		Vehicle CO_2 intensity (gCO_2/vkm)[11]	144	137	134	128

5.2. Power generation sector results

Figure 14 shows the results of the power generation sector case study. The black line represents the sector average CO_2 emission intensity pathway. The black squares represent the points that are directly derived from the scenario, the rest of the line is interpolated between these points. The intensity pathway shows a gradual decrease from 590 gCO_2/kWh in 2011 to 29 gCO_2/kWh in 2050, a reduction of 95%. The curve levels out when it approaches 2050, because it approaches the minimum emission levels of most renewable energy technologies (IPCC, 2014a). Figure 15 shows the compound annual growth rate of CO_2 intensity for eight intervals. The sectoral average intensity decreases at a low rate until 2020, then the annual reduction percentage peaks at 13% for the 2035-2040 interval and decreases back to a 7.5% annual CO_2 intensity reduction. Note that only scope 1 emissions are given a target in the power generation sector, because they represent the vast majority of emissions (>99% of total emissions for both CLP and EDF in 2010) (CDP, 2014).

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[10] CO_2 emissions are all in kt (1,000 tonne)

[11] Vkm = vehicle kilometer, one vkm equals one km driven by a vehicle, irrespective of the amount of passengers transported.

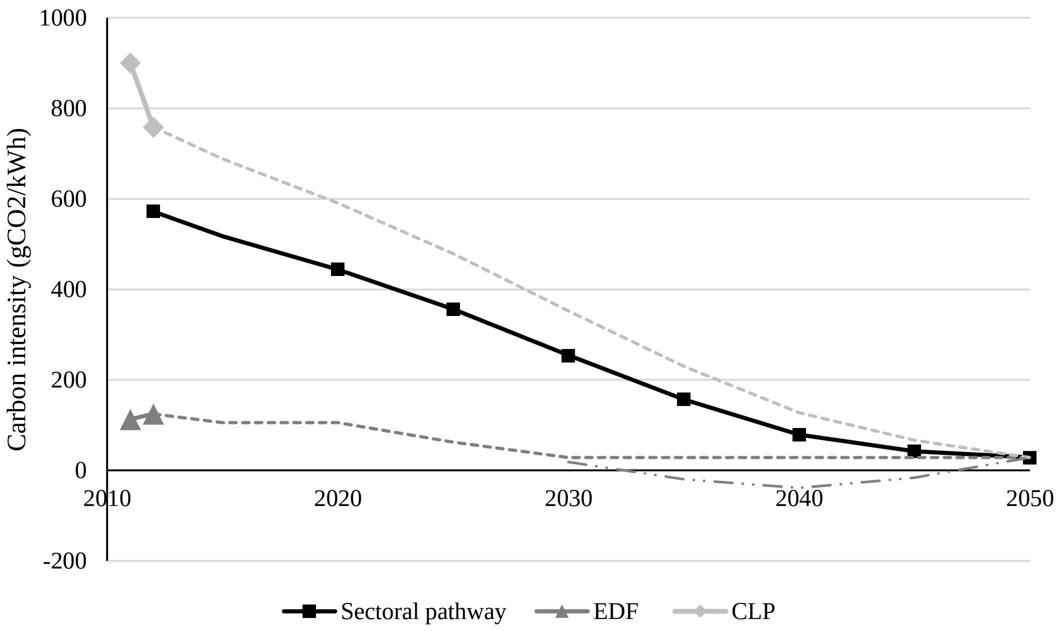

Figure 14: Scope 1 CO_2 emission intensity pathways of the power generation sector and two illustrative companies.

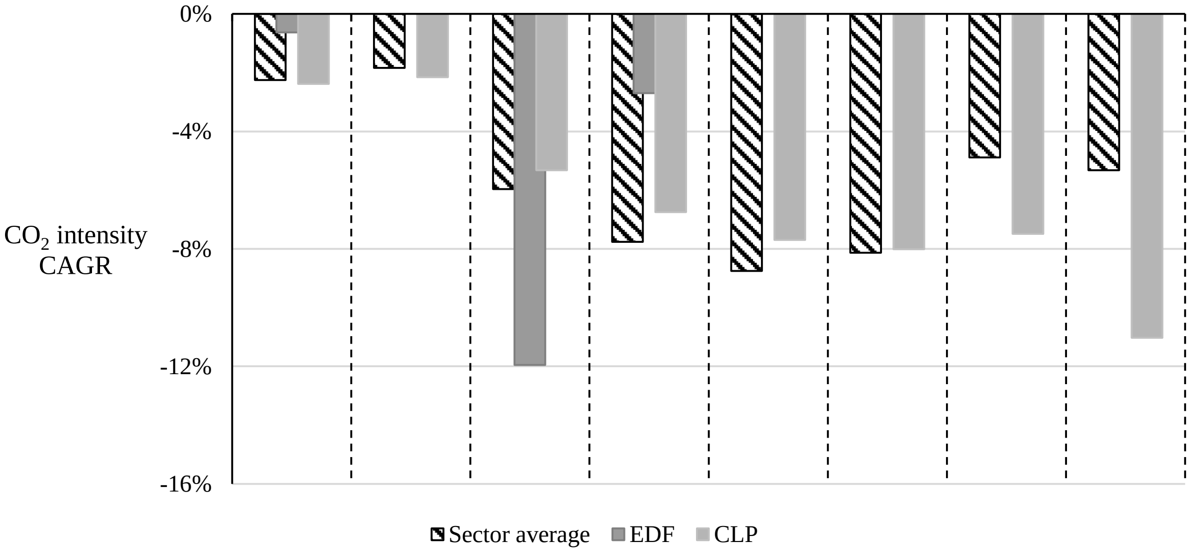

Figure 15: CAGR of scope 1 CO_2 intensity for pathways of the power generation sector and two illustrative companies.

5.2.1. CLP results

The light grey diamonds in Figure 14 show the calculated carbon intensity of electricity generated by CLP in the years after 2010 for which data is available. The amount of CO_2 emitted per kWh fluctuated significantly in the period 2010-2012, but stayed above the sector average. The most recent point is used to calculate the company intensity pathway. CLP's CAGR is similar to that of the sector average until 2045. After 2045, CLP needs to reduce its annual emissions twice as much as the sector average. The reason for this is that the CO_2 intensity approaches zero, therefore small changes result in large percentage changes.

5.2.2. EDF results

The dark grey triangles in Figure 14 show the calculated carbon intensity of EDF's electricity. The amount of CO_2 per kWh is very low (more than four times lower than average). This can be explained by the large share of nuclear (over 75% in 2012 (EDF, 2012)) in EDF's portfolio. Nuclear power emits below 100 gCO_2 per kWh, thereby reducing the average emission intensity of EDF (IPCC, 2014c).

EDF’s carbon intensity did not show fluctuations like those of CLP. Because of its low baseline level, the carbon intensity of EDF’s electricity does not need to change as much as CLP’s. However, the percentage change (as shown in Figure 15) is higher than CLP’s until their carbon intensity reaches the 2050 level in 2030. The bottom dashed line in Figure 14 shows what EDF’s pathway would have looked like if the methodology did not include the constraint that the prescribed intensity is never below the 2050 target (see Equation 1).

5.3. Iron and steel sector results

The results of the iron and steel sector case studies are shown in Figures 16 to 20. The sectoral pathway for scope 1 CO_2 emission intensity in the iron and steel sector shows a gradual decline from 2 tCO_2 per tonne crude steel in 2011 to 0.89 tCO_2 in 2050, a reduction of 55% (Figure 16). The curve shows a dent in 2020, which can be explained by the decline in crude steel demand after 2020 due to market saturation in the emerging economies (IEA, 2012a). Annual intensity reductions for scope 1 CO_2 emissions do not show any extremes and stay below 3% intensity reduction per year[12]. For scope 2 emissions, the intensity reduction between 2011 and 2050 is 94%. The CAGR of scope 2 CO_2 intensity of iron and steel between 2011 and 2050 (as shown in Figure 19) is slightly less than that of electricity, because the electricity intensity (the amount of kWh needed for a tonne crude steel) changes over time due to technology switching (IEA, 2012a). However, the intensity pathway remains very similar to that shown in Figure 14. Adding up the scope 1 and 2 emissions creates the combined pathway shown in Figure 20. Scope 2 emissions are a small part of total CO_2 emissions in the iron and steel sector.

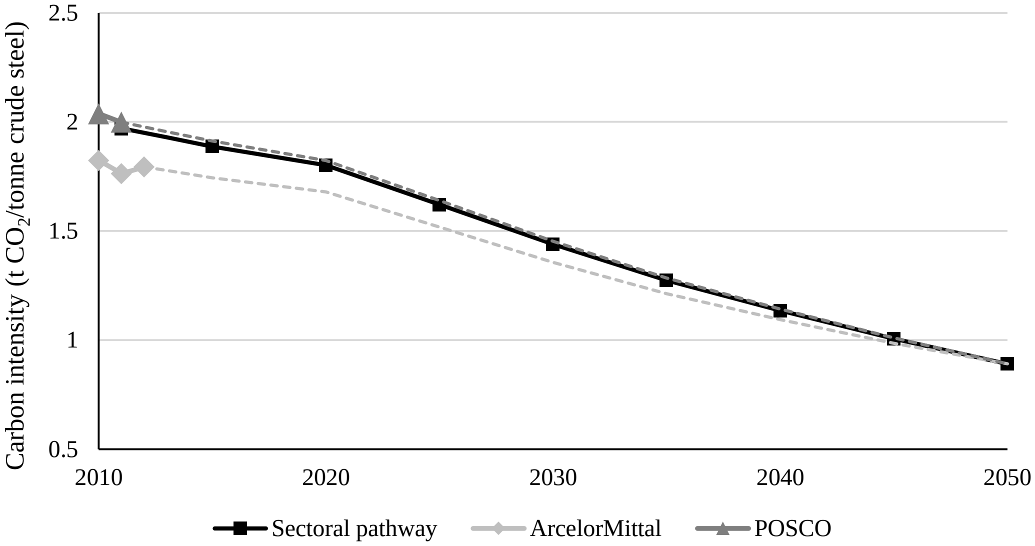

Figure 16: Scope 1 CO_2 emission intensity pathways of the iron and steel sector and two illustrative companies.

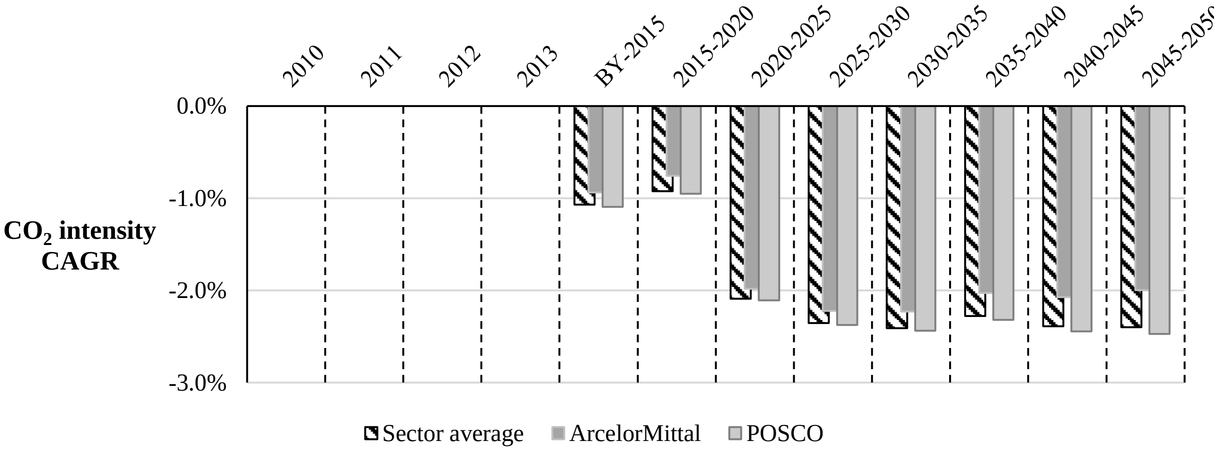

Figure 17: CAGR of scope 1 CO_2 intensity for pathways of the iron and steel sector and two illustrative companies.

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[12] The CAGR is calculated using 2011 as the base year (BY) for POSCO and the sector, and 2012 for ArcelorMittal

5.3.1. ArcelorMittal results

The light grey diamonds in Figure 16 and Figure 18 represent the carbon intensities of steel produced by ArcelorMittal which are calculated using the information in Table 9. ArcelorMittal's scope 1 CO_2 emissions per tonne crude steel are below the sector average. The dent in the sectoral intensity pathway is translated to ArcelorMittal's pathway. The CAGR for ArcelorMittal's scope 1 intensity is below that of the sector during the entire 2011-2050 period. ArcelorMittal's scope 2 GHG emissions intensity is about 50% under the sector average. As with EDF's scope 1 intensity pathway, ArcelorMittal's scope 2 pathway levels out when its scope 2 intensity reaches the 2050 sectoral intensity target. Also, the intensity reduction percentage is high because of the steep decrease in the sector average and the low company emission intensity. Figure 20 shows that ArcelorMittal's combined scope 1 and 2 intensities add up to be below the sector average. This means that ArcelorMittal's CO_2 emissions are below the 2 °C pathway, and can be considered sustainable.

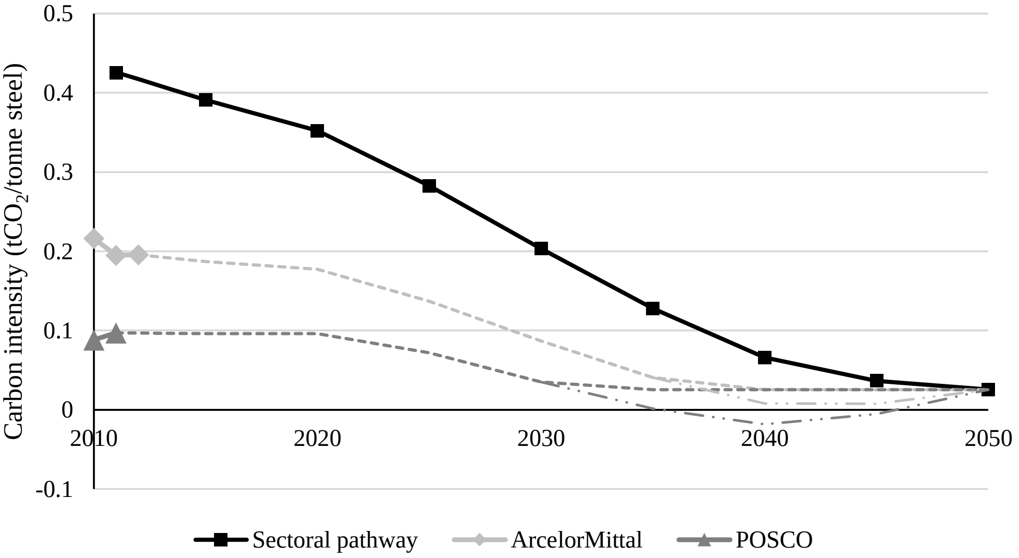

Figure 18: Scope 2 CO_2 emission intensity pathways of the iron and steel sector and two illustrative companies.

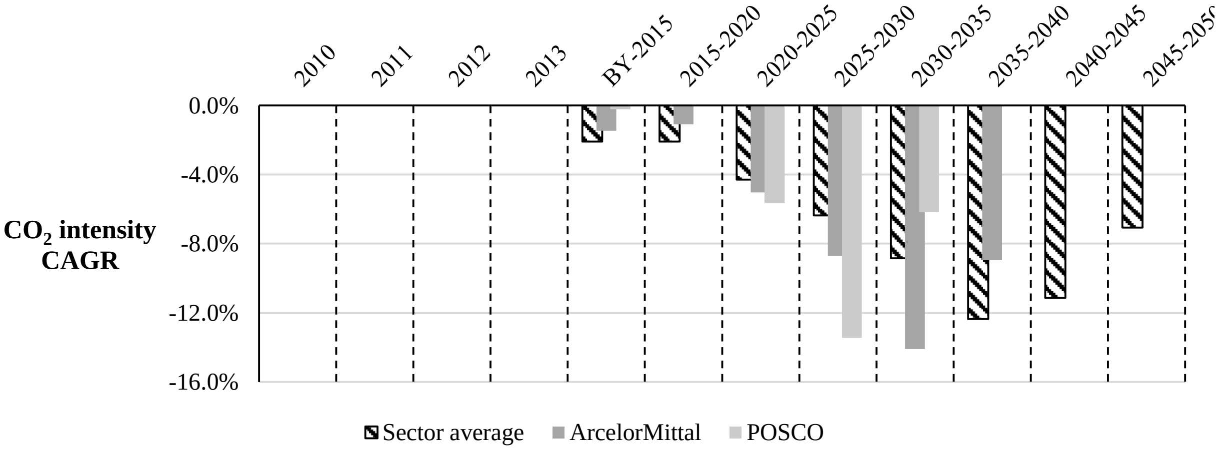

Figure 19: CAGR of scope 2 CO_2 intensity for pathways of the iron and steel sector and two illustrative companies.

5.3.2. POSCO results

The calculated scope 1 and 2 CO_2 emission intensities of POSCO are indicated in Figure 16 and Figure 18 with dark grey triangles. POSCO's scope 1 CO_2 emission intensity is slightly higher than the sector average and converges towards the sectoral average in 2050. The pathway follows the dent in the sectoral pathway. Such a dent means that POSCO can delay part of its abatement efforts until after the demand peak, enabling them to be more cost-effective. Because POSCO's scope 1 intensity is higher than

ArcelorMittal’s intensity in the base year, the annual reductions are higher, as shown in Figure 17. The CAGR is only slightly higher than the sector average. The scope 2 CO_2 emissions caused by POSCO’s steel production are extremely low (about 25% of the sector average intensity). Figure 19 shows that POSCO’s intensity pathway requires extreme intensity reductions between 2025 and 2030, and no intensity reductions from 2035 to 2050. The combined scope 1 and 2 emission intensity is below the sector average and shows a pathway similar to ArcelorMittal’s intensity pathway (Figure 20). Note that POSCO’s combined scope 1 and 2 target can be considered sustainable, although their scope 1 CO_2 emissions are not in line with a 2 °C pathway.

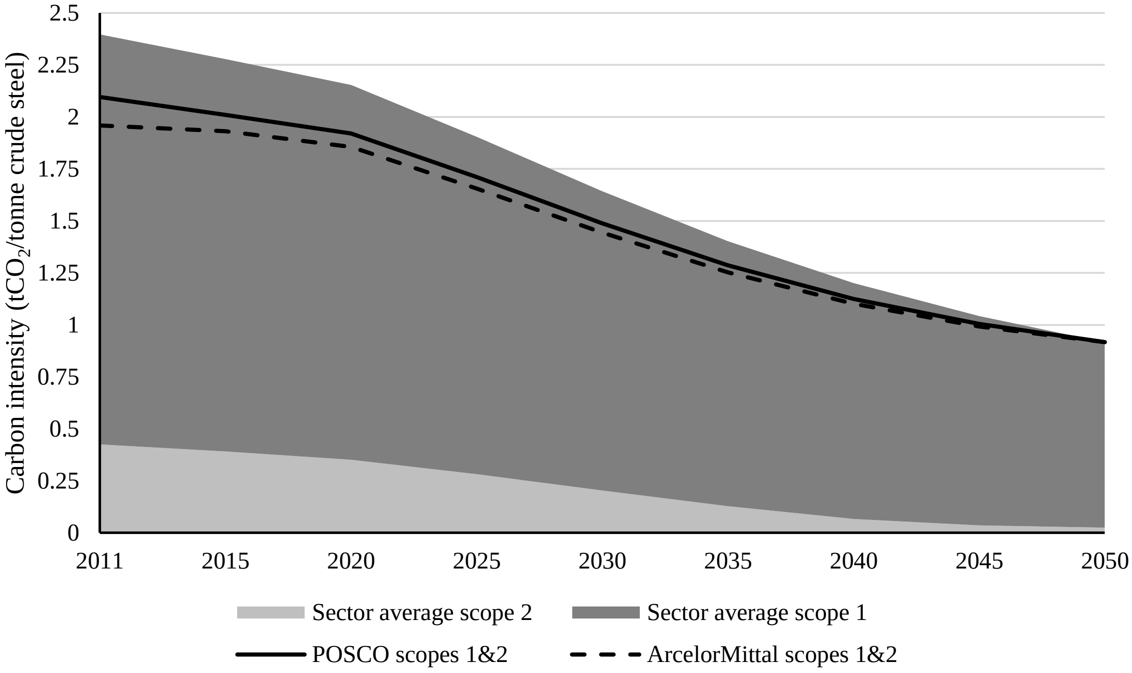

Figure 20: Scope 1 and Scope 2 CO_2 emission intensity pathway of the iron and steel sector and two illustrative companies.

5.4. Automotive sector results

For the automotive sector, calculating CO_2 emissions is slightly more complex than for the power generation and iron and steel sectors. More calculation steps are required and two sectoral pathways are used (i.e. that of the other industry sector and that of light road passenger vehicles). After calculating the scope 1 and 2 baseline carbon intensity for the two companies (and converting all monetary values to $€_{2010}$ using consumer price index data from the European Central Bank (ECB, 2014)), large fluctuations were observed. These fluctuations are often observed in monetary intensity indicators for the reasons described in section 2.2.3. Therefore, the method proposed by Randers (2012) is used to estimate a fair baseline. A trend line is fitted to the calculated values and by inserting base year 2011 in the resulting equation, the baseline value is calculated (see Figure 21 and Figure 22). For the scope 3 intensity target, a conversion step is required, because the two companies provide emissions data in gCO_2/vkm (vehicle km). The emissions per vkm are divided by the average occupancy rate (1.65 persons per vehicle (Michaux & André, 2004)) to get the desired CO_2 per pkm values.

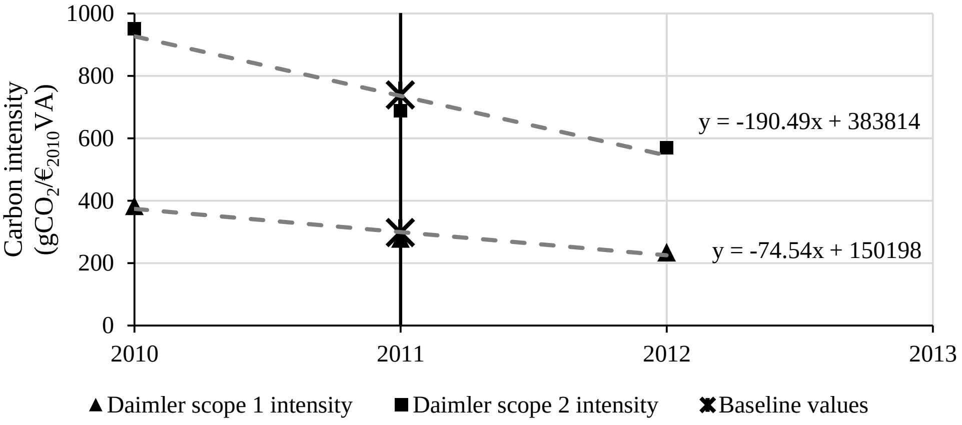

Figure 21: Estimating of baseline value for Daimler's scope 1 and 2 CO_2 emission targets.

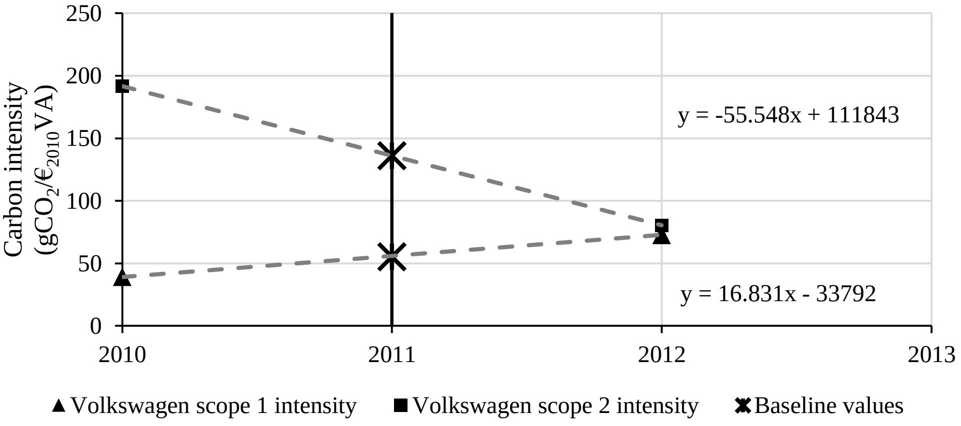

Figure 22: Estimating of baseline value for Volkswagen's scope 1 and 2 CO_2 emission targets.

The results for the two automotive case studies are shown in Figures 23 to 27. Because the activity of the sector is unknown, no sectoral pathway is constructed for scope 1 and 2 CO_2 emission intensity. Instead, a pathway is constructed using the base year value (calculated above) and the percentage intensity change calculated for the sector (see Table 8). Because the intensity reduction percentage is equal for all companies within the sector (same-reduction allocation, see section 2.2.2), the CAGR is also equal. Figure 25 shows the CAGR for scopes 1 and 2. The most reduction effort is required for scope 2 emissions between 2035 and 2040 (15.2% annual intensity reduction). For scope 1 emissions, the peak is between 2025 and 2030 (7.3% annual intensity reduction).

For the CO_2 emissions from vehicle use (scope 3), the sectoral emission intensity pathway is shown in Figure 26. The sector average CO_2 emissions per pkm for new light road passenger vehicles are 84gCO$_2$/pkm in 2011 and decrease to 15gCO$_2$/pkm in 2050. Figure 27 shows the annual intensity reduction percentage derived from the 5-year intervals. Reductions are highest in the period 2040-2045 (7.3% annual intensity reduction).

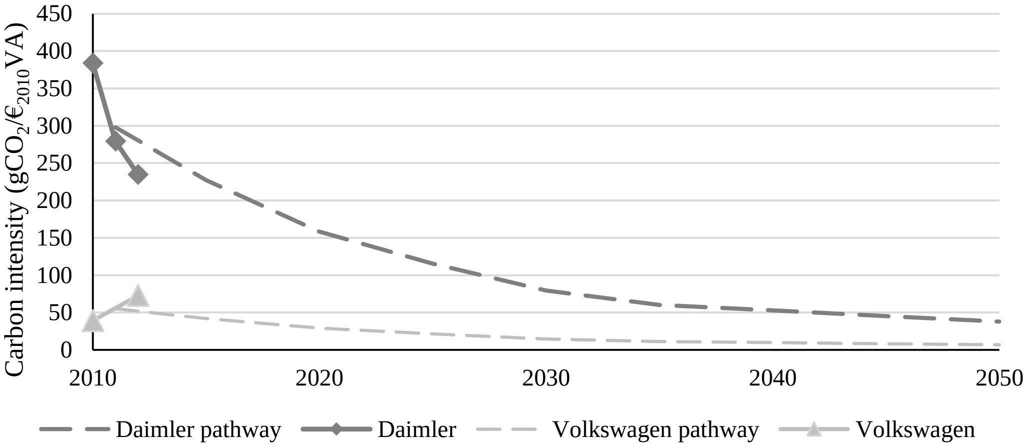

Figure 23: Scope 1 CO_2 emission intensity pathways of two illustrative automotive companies.

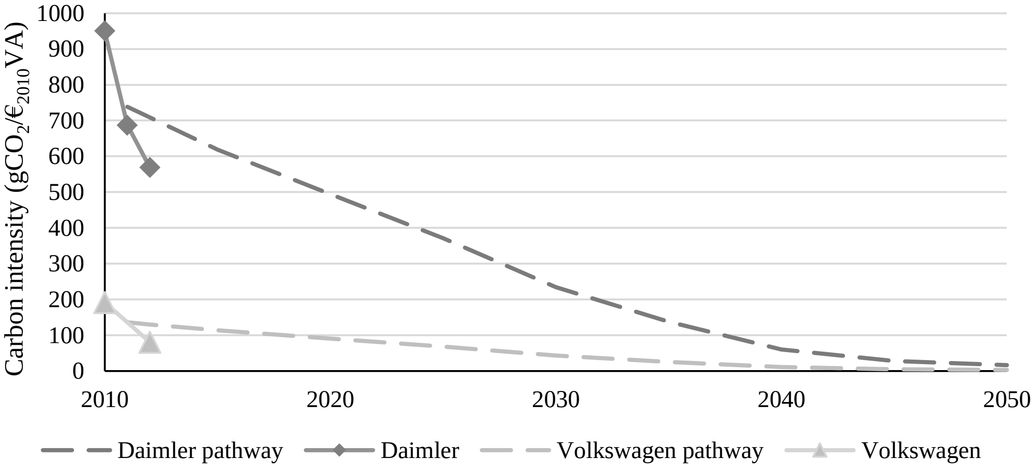

Figure 24: Scope 2 CO_2 emission intensity pathways of two illustrative automotive companies.

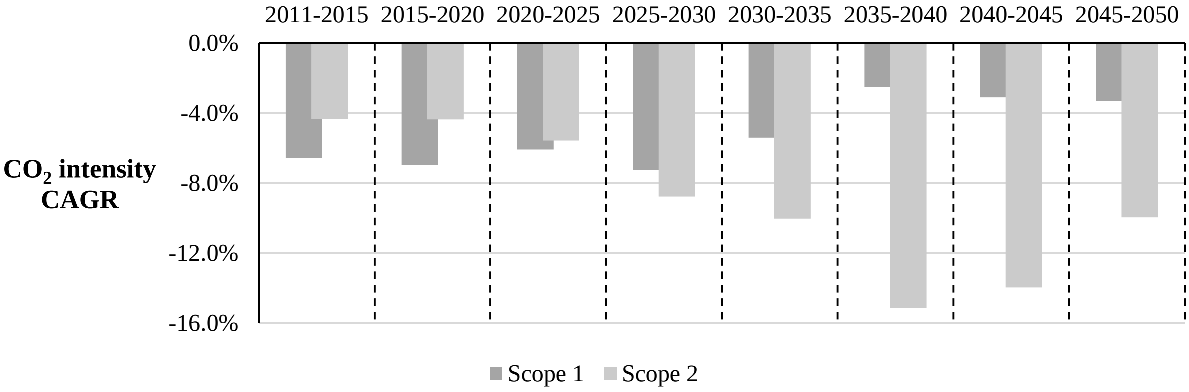

Figure 25: CAGR of scope 1 and 2 intensity for pathways of the other industry sector.

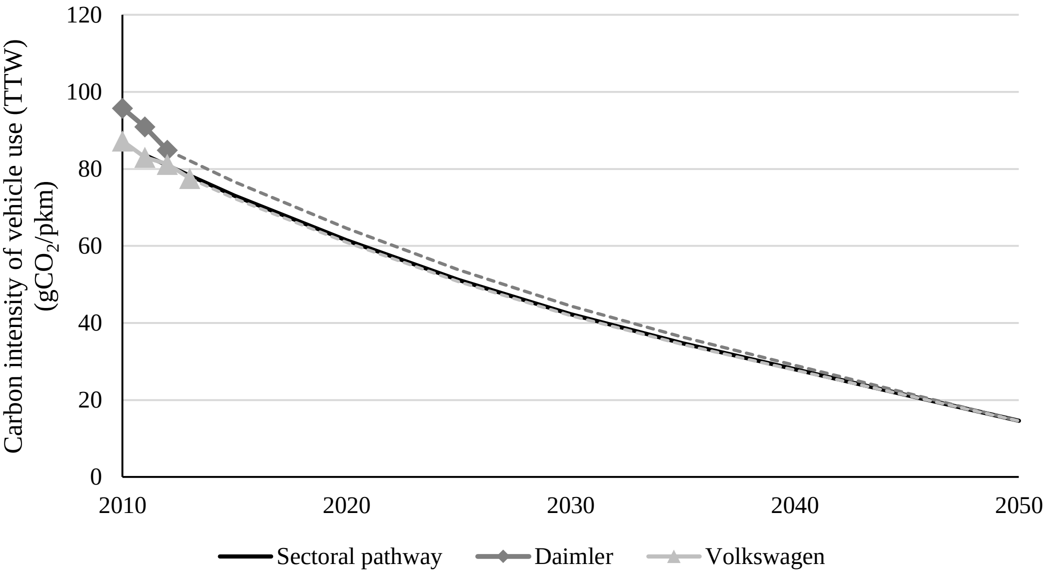

Figure 26: Intensity pathways of scope 3 CO_2 emissions from vehicle use (TTW) of light road passenger vehicle manufacturers and two illustrative automotive companies.

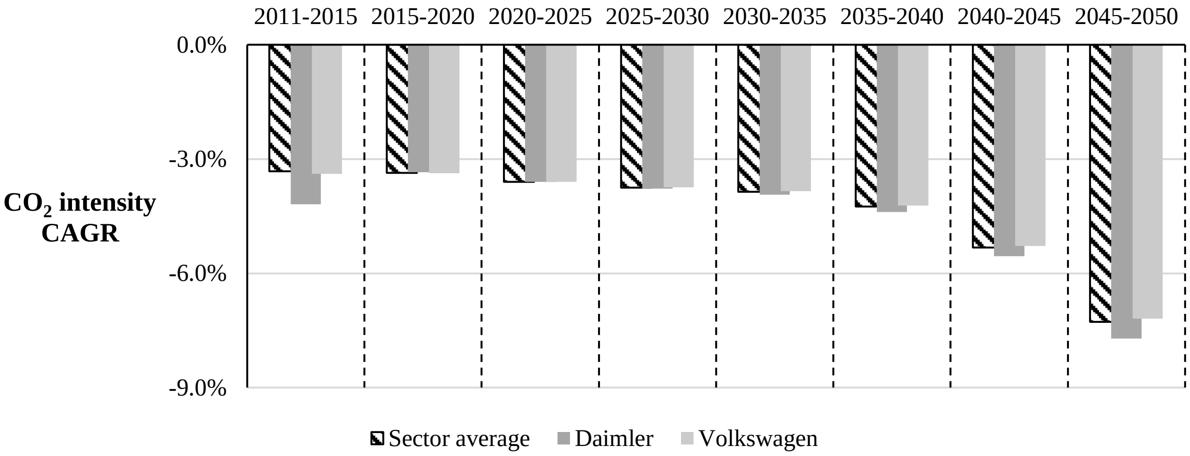

Figure 27: CAGR of scope 3 CO_2 emissions from vehicle use intensity for pathways of the light road passenger vehicle sector and two illustrative companies.

5.4.1. Daimler results

Daimler's scope 1 CO_2 emission intensity is relatively high (more than three times Volkswagen's scope 1 intensity in 2012, see Figure 23). Because Daimler's scope 1 intensity has shown a steep decrease in the years 2010-2012, the pathway derived from the 2011 base year is rather lenient; it is higher than the actual 2011 value. This means that Daimler emitted an amount of CO_2 in 2011 and 2012 that was in line with the 2 °C target. It is remarkable that Daimler shows intensity reductions of -27% and -28% for scope 1 CO_2 emissions and scope 2 CO_2 emissions respectively between 2010 and 2011. Following the sectoral pathway, Daimler's sharpest scope 1 and 2 emission intensity reductions take place from 2025 to 2030, and from 2035 to 2040, respectively.

Daimler's automobiles emit slightly more CO_2 per pkm than the sector average (Figure 26). Therefore, it needs to reduce the CO_2 emissions from its vehicles slightly more that the sector average. Like the entire sector, Daimler's efforts in reducing climate impacts from use of its products need to increase over the years.

5.4.2. Volkswagen results

Volkswagen’s scope 1 CO_2 emission intensity is relatively low, but shows a strong increase in the period 2010-2012. The company pathway requires intensity reductions that are the same percentage as the sector average and Daimler’s reductions (Figure 25). In 2050, Volkswagen’s scope 1 emissions per €$_{2010}$VA must be 7gCO_2 in order for it to be in line with the 2 °C target. It is not certain whether this is a realistic target or not. For scope 2 CO_2 emissions, Volkswagen has shown a reduction per €$_{2010}$VA until 2012. Because of that, Volkswagen’s CO_2 emissions are below the 2 °C target in 2012. The intensity pathway for CO_2 emissions from use of Volkswagen’s vehicles is similar to that of Daimler, due to the small difference in emission intensity. Also the annual intensity reductions in Figure 27 are similar to those of Daimler and the sectoral pathway.

5.5. Case study conclusions

During the data acquiring phase of the case studies, it was clear that although the SITA method disaggregates as much as possible, structural differences still exist between companies. In the power sector, some companies have geographical advantages that are not accounted for (e.g. hydro, geothermal or CCS). In the iron and steel sector, differences are caused by different shares of recycling in different parts of the world, due to faster growing demand than scrap metal is able to supply (IEA, 2012a). Although the light road passenger vehicles sector is a disaggregated sector, it still made up of several different sorts of vehicles (i.e. cars, passenger light trucks, and min-buses). This results in structural differences among companies, and targets that are lenient to one company, and stringent to another.

Table 10 summarizes the results of the CAGR analysis. Sharp intensity reductions are indicated by a darker shade of grey. The most extreme intensity reductions are in the scope 2 pathways. This is due to significant intensity reductions in the power generation sector. Especially when scope 2 intensity is relatively low, the intensity reductions are high. For some of these pathways, the reduction burden is distributed illogically over time. The pathway of EDF, and the scope 2 pathways of ArcelorMittal and POSCO reach the 2050 target in 2030, 2040, and 2035 respectively. That is the result of Equation 1, which linearly decreases the difference between the company intensity and the sectoral intensity pathway. From the company’s perspective it might be preferable to converge in another way towards the sectoral pathway in order to spread out the intensity reductions (and costs).

Table 10: 5-year interval CAGR of case study CO_2 emission intensity pathways[13].

CO_2 intensity pathway	**Scope**	**2011-2015**	**2015-2020**	**2020-2025**	**2025-2030**	**2030-2035**	**2035-2040**	**2040-2045**	**2045-2050**
Power generation sector	1	-3.3%	-3.0%	-4.3%	-6.5%	-9.2%	-12.9%	-11.7%	-7.5%
EDF	1	-1.7%	0.0%	-10.0%	-14.4%	0.0%	0.0%	0.0%	0.0%
CLP	1	-6.5%	-3.0%	-4.1%	-6.0%	-8.1%	-11.1%	-12.1%	-15.6%
Iron and steel sector	1	-1.1%	-0.9%	-2.1%	-2.4%	-2.4%	-2.3%	-2.4%	-2.4%
	2	-2.1%	-2.1%	-4.3%	-6.4%	-8.8%	-12.4%	-11.1%	-7.1%
ArcelorMittal	1	-0.3%	-0.8%	-2.0%	-2.2%	-2.2%	-2.0%	-2.1%	-2.0%
	2	-1.0%	-1.1%	-5.0%	-8.7%	-14.1%	-8.9%	0.0%	0.0%
POSCO	1	-1.1%	-1.0%	-2.1%	-2.4%	-2.4%	-2.3%	-2.4%	-2.5%
	2	-0.2%	0.6%	-6.2%	-13.5%	-6.2%	0.0%	0.0%	0.0%
Automotive sector	1	-6.6%	-7.0%	-6.1%	-7.3%	-5.4%	-2.5%	-3.1%	-3.3%
	2	-4.3%	-4.4%	-5.6%	-8.8%	-10.0%	-15.2%	-14.0%	-10.0%
	3	-3.3%	-3.4%	-3.6%	-3.7%	-3.9%	-4.2%	-5.3%	-7.3%
Daimler	1	-6.6%	-7.0%	-6.1%	-7.3%	-5.4%	-2.5%	-3.1%	-3.3%
	2	-4.3%	-4.4%	-5.6%	-8.8%	-10.0%	-15.2%	-14.0%	-10.0%
	3	-4.2%	-3.3%	-3.6%	-3.8%	-3.9%	-4.4%	-5.6%	-7.7%
Volkswagen	1	-6.6%	-7.0%	-6.1%	-7.3%	-5.4%	-2.5%	-3.1%	-3.3%
	2	-4.3%	-4.4%	-5.6%	-8.8%	-10.0%	-15.2%	-14.0%	-10.0%
	3	-3.4%	-3.4%	-3.6%	-3.7%	-3.8%	-4.2%	-5.3%	-7.2%

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[13] Sharp intensity reductions in Table 10 are indicated by a darker shade of grey.

6. Impact analysis

In 2010, global GHG emissions were approximately 49.5 $GtCO_2eq$ (IPCC, 2014c). Of this total, about 65% (around 32 $GtCO_2eq$) are CO_2 emissions from fossil fuels and industrial processes (thus excluding emissions from forestry and other land uses; FOLU emissions). 26.8 $GtCO_2$ (54%) of 2010 GHG emissions is covered by the SITA methodology. This is 84% of all CO_2 emissions from combustion of fossil fuels and industrial processes (see Figure 28). Figure 29 shows how the total emissions will be affected if all companies implement SITA targets. The non-included sectors are also shown and are expected to do their fair share of emission abatement without SITA targets. The bulk of the emission reductions are made in the power generation sector. For other sectors, the absolute emissions do not seem to reduce a lot. However, due to increasing activity, significant intensity reductions are required to meet the absolute emissions target in for example the aviation sector.

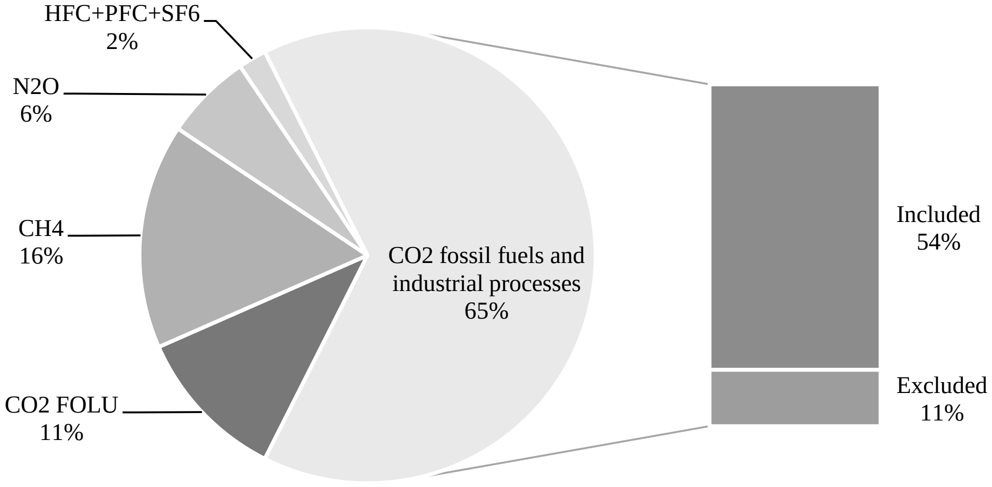

Figure 28: Share of 2010 GHG emissions included in SITA method.

The total emissions of all included sectors will be reduced by 57% (-15 $GtCO_2$) in 2050 compared to 2011 if all companies in the included sectors adapt the targets resulting from the SITA methodology. That is equal to 30% of global GHG emissions and 40% of global CO_2 emissions in 2010.

When the total of annual CO_2 emissions for the years 2011 to 2050 is added up, the cumulative amount of emissions, or carbon budget, is calculated. Climate science has published extensively on the topic of carbon budgets (Allen, Frame, Huntingford, et al., 2009; Hansen, Kharecha, Sato, et al., 2013; IPCC, 2014c; Meinshausen et al., 2009). The cumulative amount of CO_2 emissions is a relatively good proxy for the probability of meeting the 2 °C target (Meinshausen et al., 2009). According to IPCC Working Group I (2013) the total carbon budget since the industrial revolution (1880) is 3,670 $GtCO_2$ (66% chance of limiting to 2 °C) (see Figure 30). Working Group III estimated that the carbon budget for the time frame 2011-2100 should be between 630 and 1180 $GtCO_2$ (with a 66% probability of meeting the 2 °C target), and for the time frame 2011-2050 it should be between 550 and 1,300 $GtCO_2$ (IPCC, 2014c). The cumulative amount of CO_2 emissions resulting from the pathway shown in Figure 29 is 1,055 $GtCO_2$. This means that the SITA targets are in line with the 2 °C target. Note that the amount of maximum allowable CO_2 emissions for the time frame from 2011 to 2100 are 1,180 $GtCO_2$. This means that after 2050 negative CO_2 emissions might be necessary to avert catastrophic climate change.

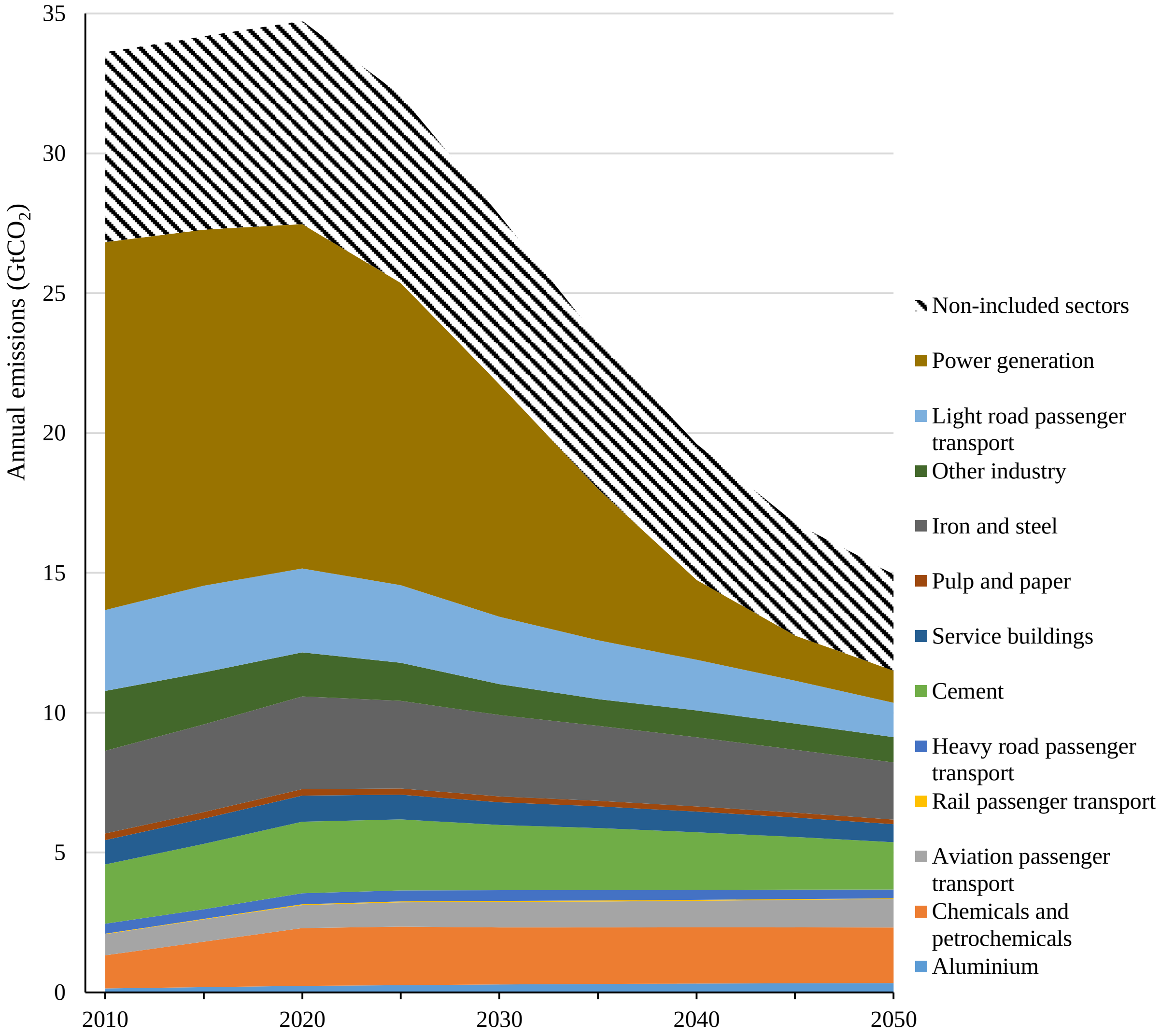

Figure 29: Total absolute direct emissions of included sectors.

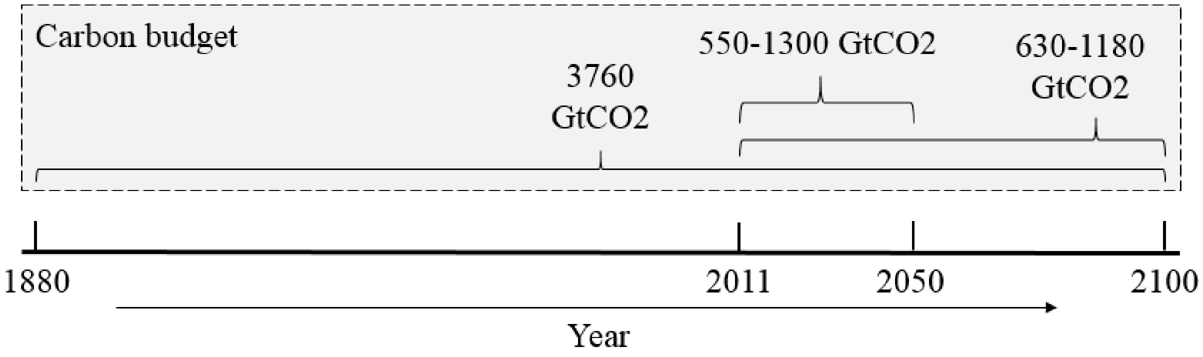

Figure 30: Carbon budgets for different time frames (based on IPCC (2013, 2014c)).

7. Sensitivity analysis

This section investigates the effects of decisions made in the development of the SITA method. Three aspects are studied: the effect of choosing an alternative scenario to construct the sectoral intensity pathway, the effect of choosing an alternative activity indicator, and the effect of using a different interpolation technique.

In order to assess the effects of choosing another scenario, the sectoral intensity targets for 2050 are calculated using the 2012 edition of the 2DS from *Energy Technology Perspectives 2012* (ETP2012) (IEA, 2012a). These ETP2012 targets are compared to the ETP2014 targets. Besides this 2050 target comparison, the pathway of one of the case studies is recalculated using ETP2012 data.

To assess the influence of the chosen activity indicator, the intensity pathway from one of the case studies is recalculated using monetary indicators instead of physical indicators for activity, as if the physical activity data was unavailable. The impact this has on the resulting target and company intensity pathway is analysed.

As stated in section 4.4, data gaps (i.e. when the scenario does not provide the CO_2 emissions or activity for a given year) are filled using linear interpolation. However, there can be reasoned that CO_2 emissions and activity do not increase or decrease linearly, but show exponential growth or decline. Therefore, the effects of using exponential instead of linear interpolation is analysed by applying this interpolation technique to the case studies.

7.1. Alternative emission scenario: ETP2012

The SITA method developed in this thesis uses the 2014 edition of the 2DS scenario. However, this 2014 edition has been released recently. If this study was conducted a few months earlier, the most recent version of 2DS would have been the original 2012 edition (IEA, 2012a). This section assesses the differences between the two versions and the impact on the SITA method.

First, the shares of different energy sources in total primary energy demand in 2050 are compared. Figure 31 shows the result of this comparison. The total energy demand in 2050 is expected to be 681 EJ in the ETP 2014. It was 697 EJ in ETP2012. This difference of about 2% can be explained by the lack of CO_2 emission reductions since the ETP2012 report. Because current emissions are above the 2 °C pathway, 2050 CO_2 emissions need to be lower in order to compensate. This compensation is also seen in the 2050 energy mix. The fossil fuels have a lower projected share in energy supply, while biomass and renewables have a larger projected share. Furthermore, nuclear has a decreased share. The average change per primary energy source is around 10%.

When looking at the sectoral emissions in Figure 31, a similar conclusion is drawn. The changes in annual emissions are significant for the included sectors. Note that not all sectors are included in the figure. This is due to limited data availability of the ETP2012 2DS scenario. The sectors that are affected mostly are the power generation sector (-51% CO_2 emissions) and the aviation sector (+58% CO_2 emissions). The average change in allowed 2050 emissions of all included sectors is 28%.

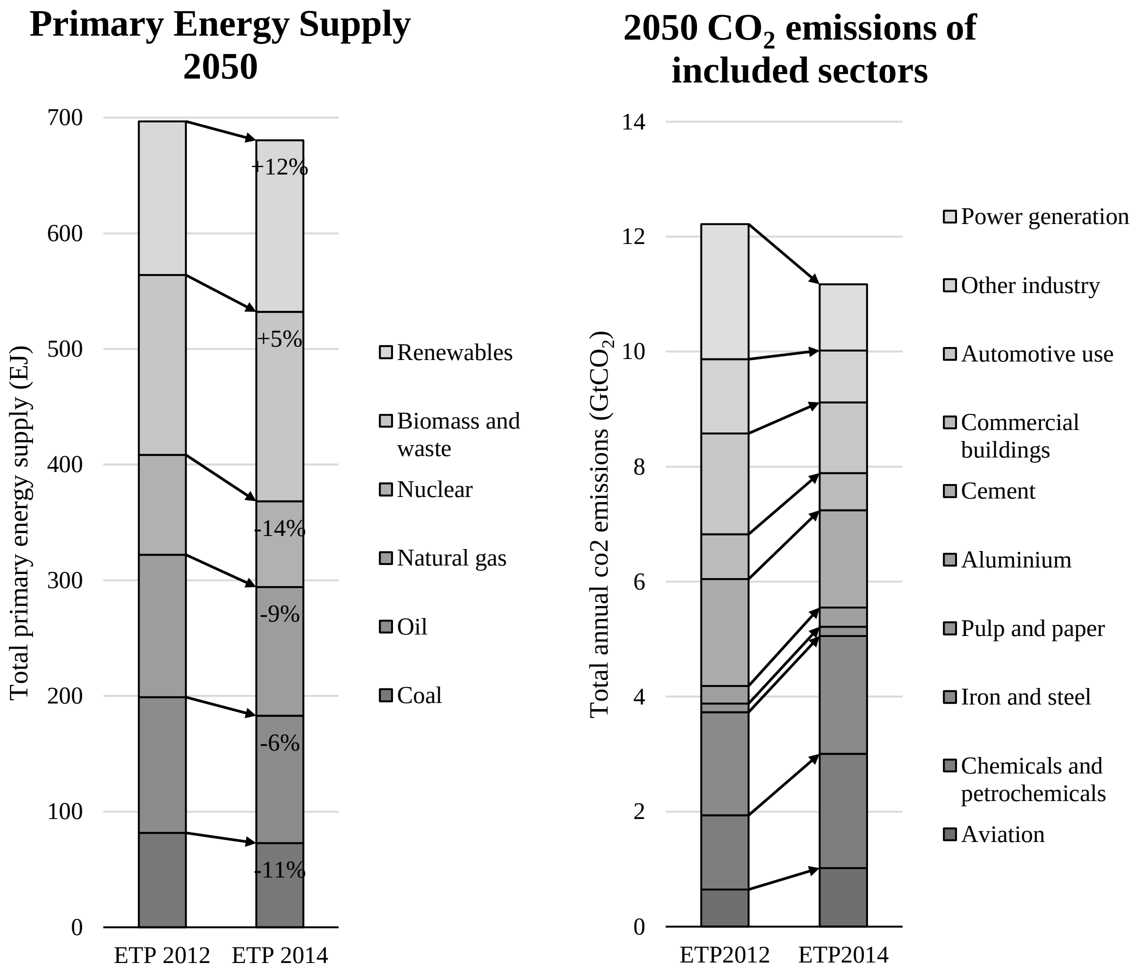

Figure 31: Primary energy supply and sectoral CO_2 emissions of ETP2012 and ETP 2014.

Assuming that the differences between scenario versions originate in new scientific insights, Figure 31 shows that a lot of uncertainties still exist in the technological models and parameters that produce these forecasts. The differences in sector results by the same modelling group using the same model in versions that are only two years apart are remarkably high. According to IEA, the major causes of differences between their results are two recent developments: the emergence of new supplies of natural gas, and the severe nuclear accident at the Fukushima Daiichi nuclear power plant (IEA, 2014). Furthermore, coal and petroleum are segregated into more fuel types in their industry model, resulting in more accurate CO_2 emissions estimations.

In order to assess the impact of a scenario update on sectors and their allocated emissions, the sectoral carbon budgets are calculated for different time frames using the ETP2012 and ETP2014 2DS scenarios. The focus is not on absolute budgets, but on sectoral shares in the total budget for a certain time frame. This to account for the lower total carbon budget that was left when ETP2014 was developed. Figure 32 shows the shares of different sectors[14] in the carbon budget of different time frames. The inner circle represents ETP2012, and the outer circle represents ETP2014. For the short term carbon budget (2011-2020), ETP2012 and ETP2014 show similar shares of the sectors. When a later time frame is analysed, the differences between the two scenarios increase. For the 2011-2020 time frame, the share of a sector on average changes 0.47 percentage points in the scenario update. For the 2021-2030 time frame, that is 0.72 percentage point, for the 2031-2040 time frame, that is 1.13 percentage point and for the 2041-2050 time frame, that is 2.05 percentage point.

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[14] Note that the sectors are different than the SITA sectors, due to limited data availability of the ETP2012 2DS.

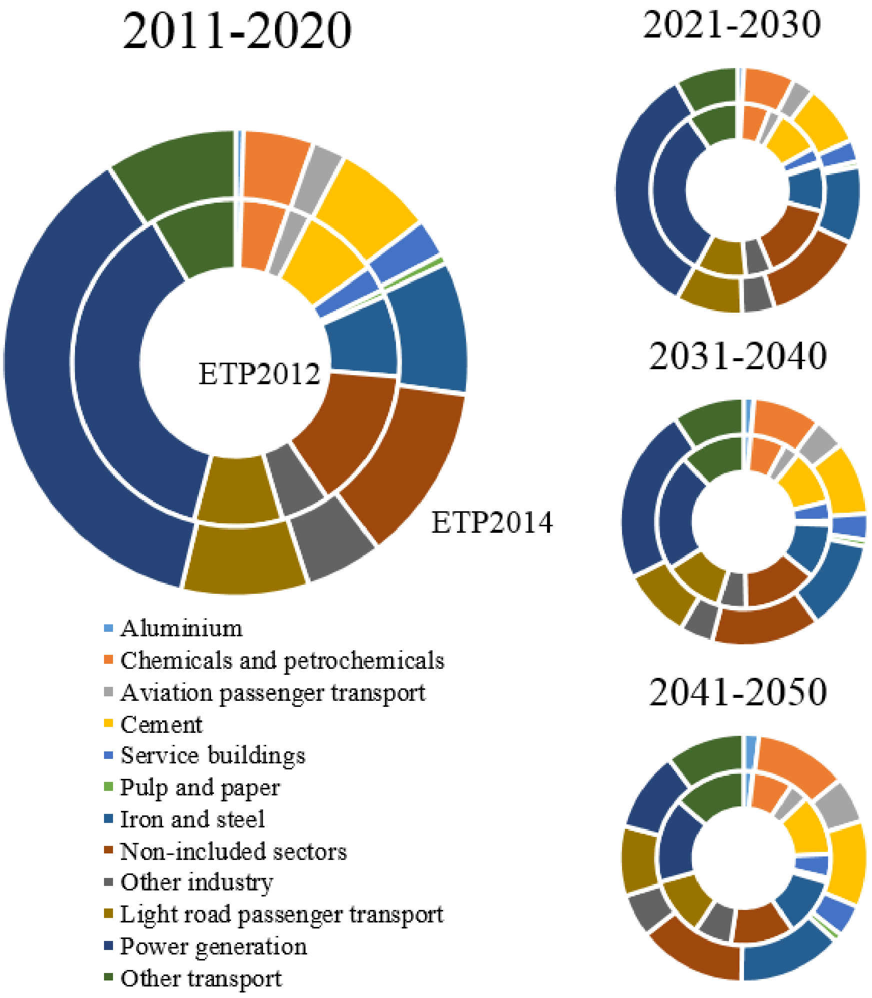

Figure 32: 2DS carbon budgets according to ETP2012 and ETP2014 for different time frames.

This means that although the 2050 targets have been altered significantly in the scenario update, this does mostly impacts long-term results, and only very slightly changes the short-term sector share in the annual carbon budget.

In order to assess the impact of the scenario change for an individual company, the intensity target of CLP is recalculated using the ETP2012 2DS scenario. A power generation company is selected because the emissions of that sector changes most of all sectors. Figure 33 shows the two intensity pathways for CLP calculated with the ETP2012 and ETP2014 2DS scenarios. Although the 2050 intensity target shows a large relative change for the 2014 scenario as opposed to the 2012 scenario (49 percent lower), the overall pathway for CLP is similar. The largest deviation between the two pathways is in 2020, when the two lines are 47 gCO_2/kWh apart. If CLP has set the target to reduce its scope 1 CO2 intensity by 16% in 2020 from base year 2012 (which is in line with the ETP2012 pathway), it would have to adjust its target to 22% in 2020 from base year 2012 in order to be in line with the ETP2014 pathway. This significant change due to a scenario update could be a reason for companies not to update their initial targets.

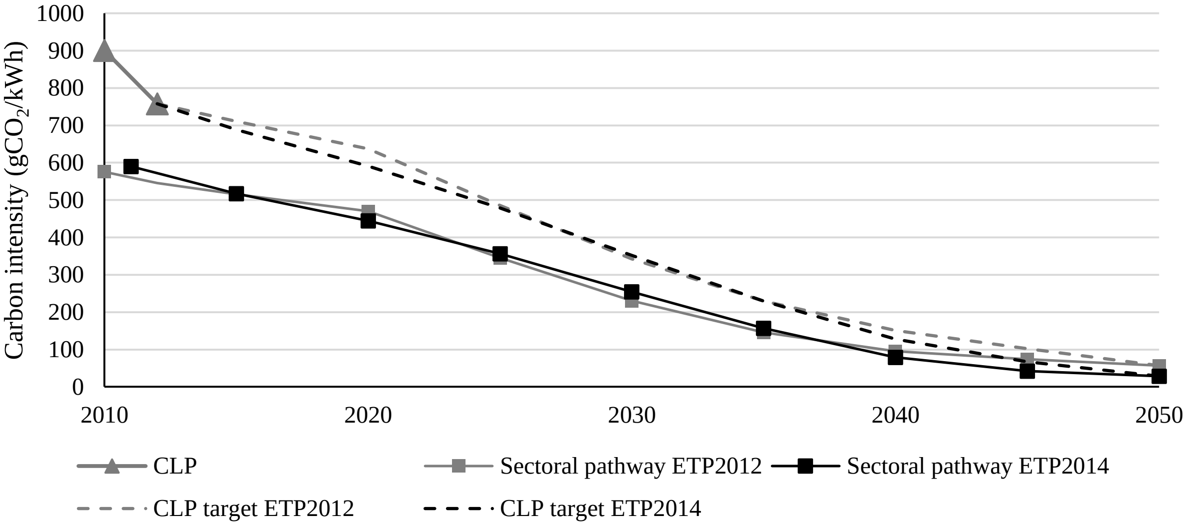

Figure 33: Scope 1 CO_2 intensity pathway of CLP based on ETP2012 and ETP2014.

7.2. Alternative activity indicator: VA instead of crude steel

In order to assess the effect of the chosen indicator, one of the case studies is selected and recalculated using a different activity indicator. POSCO steel company is chosen because it reports enough data in its annual report to calculate the VA[15]. Using the same methods as for the chemicals and petrochemicals sector, a new sectoral intensity pathway is constructed. This pathway is then used to recalculate the company intensity pathway.

Figure 34 shows the resulting pathways. For scope 1 CO_2 emissions, the pathways show a similar curve. Because VA was lower in 2011 than in 2010 and the amount of CO_2 emitted increased, the monetary intensity (in CO_2/VA) peaks in 2011. The scope 1 monetary intensity target for 2050 is significantly lower than the physical intensity target. This is due to economic growth. The IEA's GDP growth assumptions result in 263% growth from 2010 to 2050, while the expected growth of crude steel production is only 90% (IEA, 2012a).

For the scope 2 emissions, the intensity pathways show dissimilar curves. The physical intensity pathway shows a practically flat line until 2020, followed by a decreasing curve until 2035, and levels out until 2050. The monetary intensity curve steadily decreases to 5% of 2011 intensity in 2050. However, when looking at Figure 18, which also includes the sector average, the physical intensity pathway is put into perspective. Because the intensity in 2011 is already relatively low, small fluctuations are magnified. Compared to the sectoral pathway, these fluctuations are only small. Furthermore, the levelling out from 2030 is because POSCO will have reached the 2050 target by then already. The monetary pathway continues because the percentage change in the sectoral pathway is applied to POSCO, not taking the initial intensity into account. Therefore, the targets could very well be below what is technically and economically possible (at the projected carbon price).

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[15] By adding up the employee compensations, depreciation, operating income, and (non-income) taxes, like done by Lieberman & Kang (2007)

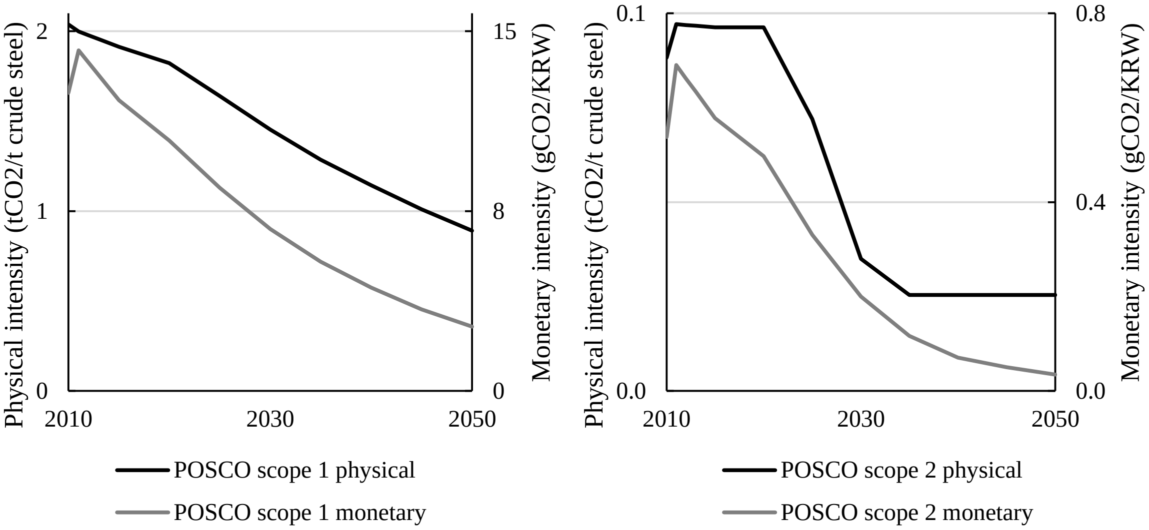

Figure 34: Comparison of physical and monetary pathways for POSCO.

A large part of the differences in the pathways above might be explained by the difference in boundary of the sectoral activity data. The physical activity is sector-specific (i.e. tonne of crude steel produced), while the monetary indicator is for the global economy as a whole. This is shown in Figure 35. On the short-term the indicators show similar growth. On the long-term, however, the physical growth and the monetary growth show a decoupling. This is due to the market saturation effects mentioned in section 2.2.3.

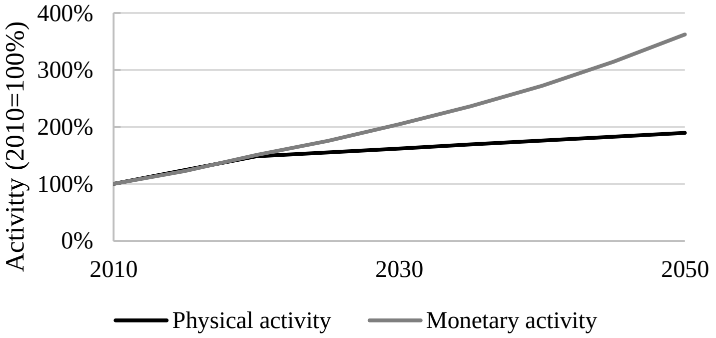

Figure 35: Physical and monetary activity for the iron and steel sector.

If POSCO would implement the targets above, it would most likely convert the intensity targets to absolute emissions so they can determine what abatement measures are required to meet the target. In this conversion step, the difference between physical and monetary indicators becomes apparent. In order to analyse this, the intensity targets are converted to absolute CO_2 emissions. However, as shown in chapter 2, this requires activity predictions. In order to make predictions, both short-term and long-term trends are averaged. Although this may not result in robust predictions, it will suffice for this illustrative purpose.

POSCO plans to produce 37.7 Mt of crude steel in 2014, compared to 36.4 Mt in 2013 (Lee & Park, 2014). This is an increase of 3.5%. From 1973 to 2003, the average production growth rate was 14.1% per year (Lieberman & Kang, 2007). The average of these two percentages is an annual growth of 8.8%. This production growth is assumed to continue until 2030. Estimating a VA growth expectation is more complicated. The company does not calculate its VA in its annual reports, and does not publish expected growth or decline of VA. Therefore, POSCO's VA is assumed to be linked to its gross profit (like assumed by (Randers, 2012)). By fitting a trend line to the gross profit of the year 2010 to 2013, the annual decline of gross profit is estimated (see Figure 36) (Google Finance, 2014). The annual decline is 1.3% per year. Because this might concern a temporary decline, it is averaged with the long-term growth of POSCO’s VA. POSCO’s VA from 1973 to 2003 grew 8.9% per year (Lieberman & Kang, 2007). The average of long-term and short term growth is 3.8% per year.

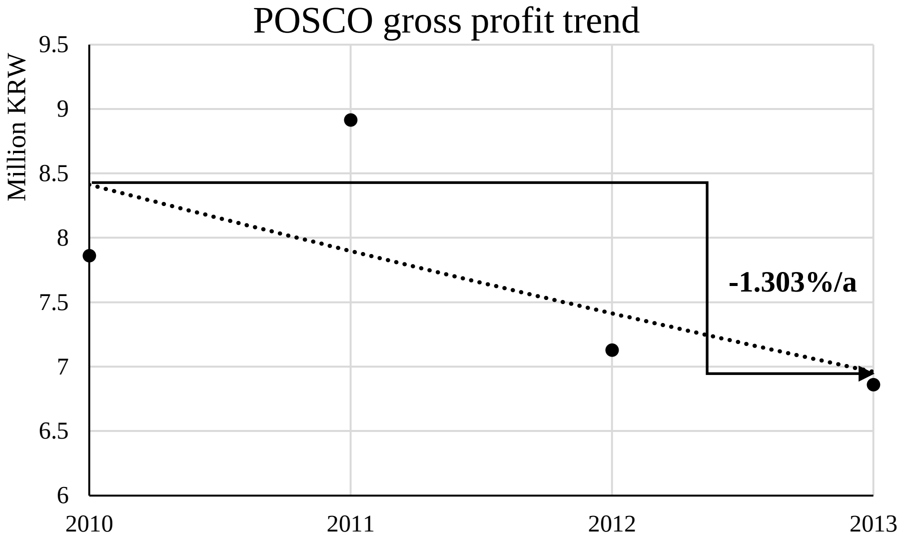

Figure 36: CAGR of POSCO's gross annual profit trend from 2010 to 2013.

Using the 8.8% physical activity growth and the 3.8% monetary activity growth, absolute emissions are calculated. They are calculated until 2030 because that is considered a reasonable time frame for business decisions and therefore an appropriate timeframe for absolute CO_2 emission targets. Figure 37 shows the two emission pathways. The pathway constructed using a physical intensity indicator shows that although the intensity is reduced, increased production results in an increase of emissions to 361% of 2011 levels. The monetary pathway shows the effect of a VA growth that is slightly larger than GDP growth on CO_2 emissions (a 6% growth from 2011 to 2030). The effect of choosing a different intensity indicator for POSCO is 191 $MtCO_2$.

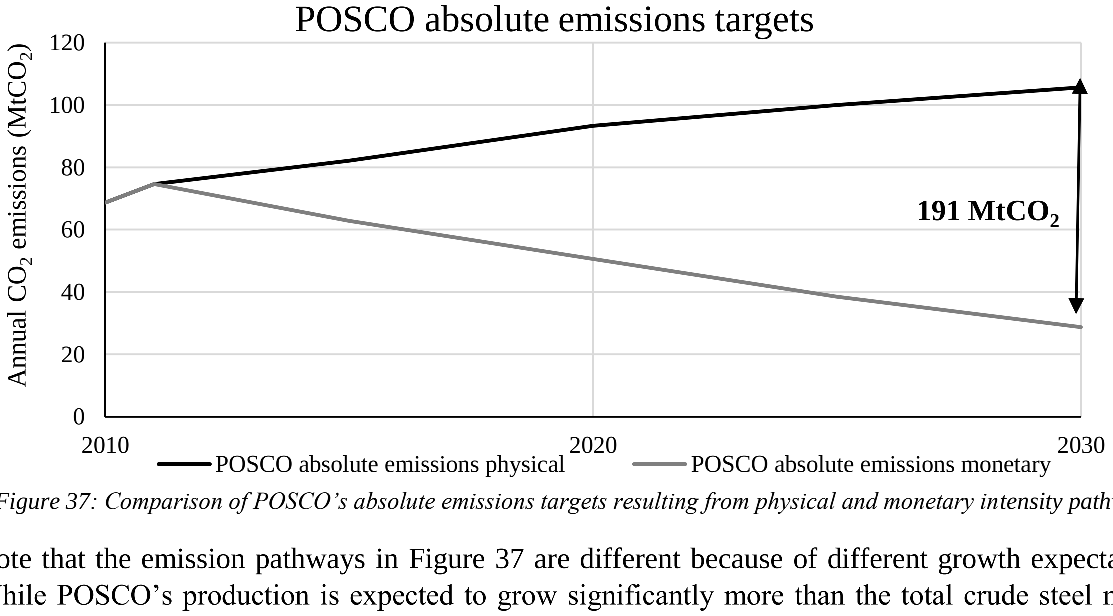

Figure 37: Comparison of POSCO’s absolute emissions targets resulting from physical and monetary intensity pathways.

Note that the emission pathways in Figure 37 are different because of different growth expectations. While POSCO’s production is expected to grow significantly more than the total crude steel market (resulting in their market share growing from 2.5% in 2011 to 9.2% in 2030), POSCO’s VA only grows slightly more than GDP over that period (which is expected to grow an average 3.7% per year). The difference between sectoral VA growth and GDP growth is most likely the cause of this discrepancy.

The results from this analysis show that there is a significant effect of using a different activity indicator. The pathways constructed using VA as activity indicator do not account for current performance and assume wrongfully that sectoral VA grows equal to GDP. Furthermore, VA shows heavy fluctuations and this may result in targets that are extremely different to the physical-based targets.

7.3. Alternative interpolation technique: exponential

For the sake of simplicity, the 5-year interval data is interpolated linearly. However, a good argument can be made to use exponential interpolation instead. Perhaps the most valid reason for using exponential interpolation instead of linear interpolation is that growth and reduction are often exponential by nature (e.g. specific energy reduction (Blok, 2007)). By interpolating linearly between points on an exponential path, the resulting interpolated pathway shows a fluctuation in annual growth as shown in Figure 38. From a business perspective, sticking to such a pathway is illogical because investments in abatement technologies have to increase substantially every 5 years and then decrease again.

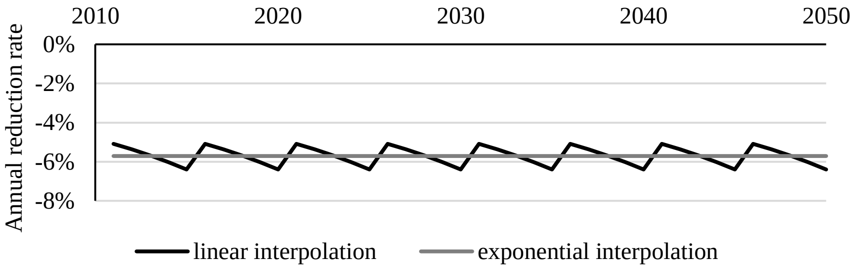

Figure 38: Annual change in pathways constructed using linear and exponential interpolation between 5-year intervals on an exponential pathway.

To see how this effect is reflected in a company intensity pathway, the power sector case study annual scope 1 intensity reductions are recalculated using exponential interpolation. Figure 39 shows the different pathways. Although the annual intensity reduction still differs substantially for the 5-year terms, the most extreme reductions are brought down from 15% to 12% and from 14% to 11% in 2025 and 2050, respectively. Note that the annual reductions for the intervals are the same as the CAGR in Figure 15.

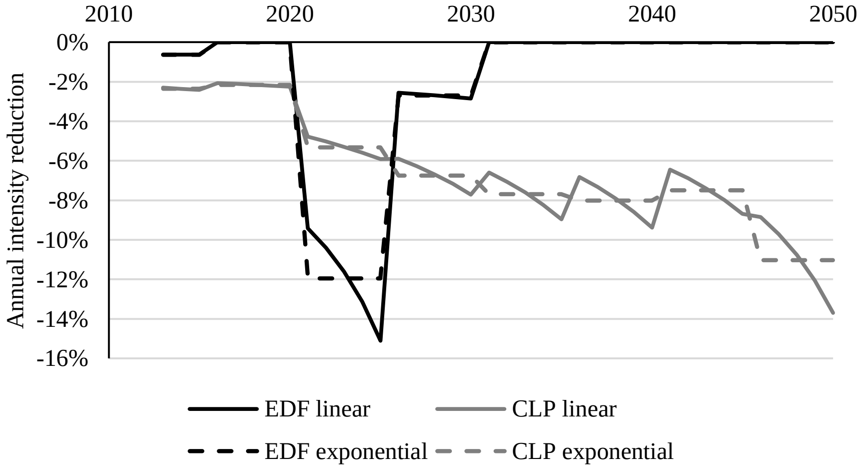

Figure 39: Annual intensity reductions of two illustrative power sector companies using linear and exponential interpolation.

Applying exponential interpolation results in more feasible intensity pathways for companies. However, the pathway still shows substantial fluctuation due to the sectoral pathway fluctuations. Since companies often choose an intensity in a certain year as a target (and thus do not necessarily stick to the prescribed pathway), these fluctuations do not necessarily have to be a problem for companies (CDP, 2013a).

7.4. Sensitivity analysis conclusions

The sensitivity analyses have shown that using another GHG emission scenario can severely impact the SITA targets. The differences between the ETP2012 and ETP2014 2DS scenario are relatively small, when comparing them (Figure 31) to the other scenarios analysed in section 4.2 (Figure 12). However, these small differences result in significant changes in 2050 sectoral targets of up to 58% (for the aviation sector).

The effect of using a monetary activity indicator, such as VA, instead of a physical indicator, such as tonne crude steel produced, is significant. However, the magnitude of this effect only is apparent when the intensity targets are converted into absolute emissions. Although the analysis is only applied to one case study, this illustrative example shows that a monetary indicator is influenced by other factors than production alone and that a difference between the growth of sectoral contribution to GDP and GDP itself can result in targets that are too ambitious or too lenient.

The effects of using exponential interpolation instead of linear interpolation are minimal. However, the CAGR analysis shows that there are strong fluctuations in growth rate of most sectoral and company CO_2 intensity pathways.

8. Discussion

This section discusses the methods used and the results presented in the previous chapters. First, the strengths and advantages of the SITA method are presented. Second, the limitations of the SITA method are discussed and compared to other methods. Finally, suggestions are made for further research.

8.1. Strengths and advantages

Although the SITA has limitations, there are plenty of strengths to the method. Furthermore, when compared to the existing methods described in chapter 3, SITA has several advantages.

Societal impact

The SITA method impact analysis has shown that if all companies in included sectors were to change their practices to follow their prescribed SITA pathway, their CO_2 emissions will be reduced to 57% of 2011 levels. The SITA method allows companies to not only target their scope 1 emissions, but also their scope 2 emissions.

The negative impact of emission abatement is primarily the costs. As the cost-effectiveness is used as the allocation criterion in the model used to construct the 2DS scenario, total costs to society are minimal. This means that the reduction of wealth is minimized and the problem of climate change is tackled in the most effective way.

Adequate for corporate target-setting

The primary application of the SITA method is its use by companies to set GHG emission targets. Therefore it is important that the method meets the various needs of companies that are engaged or want to engage in voluntary climate action. The SITA method requires a relatively small amount of company data, it determines a company's fair share in global reduction efforts, it allows for growth, and it does not penalize early movers.

The SITA method does not require companies to submit large amounts of data. Only their CO_2 emissions and their activity of the selected base year are necessary for most companies to set SITA targets. For companies that are in homogeneous sectors, the VA trend for a range of years needs to be determined in order to account for fluctuations. This requires more information, but companies usually have this data easily available. For the light road passenger vehicle manufacturers, additional data is required about their products. However, this vehicle data is usually also already available. This enables companies to calculate their intensity pathways and set emission targets with relative ease.

The SITA method is able to define a company's fair share in voluntary climate action towards the 2 °C target. By prescribing an intensity pathway, companies know what their emissions should be in order for them to be considered sustainable. Although there is no consensus on what a fair share is in the context of climate change, the SITA method suggests a definition using consistent reasoning. By setting their targets with the SITA method, companies can prove that their targets meet the requirements for limiting global warming to 2 °C.

Because the SITA method uses intensity targets rather than absolute targets, companies are able to grow without being constrained by their emission target. Likewise, a company of which the activity reduces is allowed fewer emissions in the future. This target flexibility increases the likelihood of companies to implement the SITA targets.

Contrary to allocation methods based on historical emissions (such as that used in the EU ETS), the SITA method does not penalize early movers. A company that already has a low carbon intensity (such as EDF; see section 5.5.2) is not required to reduce the same percentage of emissions as a company that has a high carbon intensity.

Adequate for NGO monitoring
For NGOs, the value of the SITA method is not in setting targets for themselves, but to determine what a sustainable emission target for a specific company should be. Using the SITA as a benchmark, NGOs can create performance indicators for companies. By reporting the performance of individual companies, they incentivise bad performing companies to adjust their targets.

Method flexibility
An advantage of the SITA method is that it is based on an integrated model. By updating assumptions and parameter values the model can be updated to represent state-of-the-art knowledge. Also, the SITA method can be based on another scenario. The next section describes possible areas of improvement.

8.2. Limitations

Although all methodological steps are taken with caution and by sound logic reasoning, the SITA method comes with several weaknesses and limitations. The most important are the excluded sectors, remaining structural difference within sectors, not accounting for geographical differences, limited scope 3 coverage, exclusion of non-CO_2 GHGs, complexity of the method, the use of VA as activity indicator, and the lack of conformity with existing policies.

Excluded sectors
From the aggregated IEA sector energy conversion, only power generation is included. This means that the oil and gas extraction and refining sectors, and the mining and quarrying sector (including coal mining) are excluded from the SITA method. These sectors are responsible for significant amounts of GHG emissions (9.6% of global GHG emissions in 2010 (IPCC, 2014c)). However, including these sectors is difficult for two reasons: a lack of data, and large uncertainties about future developments. Although LCA studies are conducted, the results from these studies show a large range of different estimates (Everts, 2008; ICCT, 2010; Jacobs Consultancy, 2012; NETL, 2011; Norgate & Haque, 2010). This range is the result of uncertainties about fugitive emissions and a lack of a global perspective in these studies (IPCC, 2014c). Furthermore, the recent technological developments in these sectors (e.g. hydraulic fracturing, enhanced oil recovery etc.) and a switch to less accessible sources (such as oil from bituminous sands) result in a lot of uncertainties for the future of these sectors (Dale, 2010; Yergin, 2012). On the one hand, intensity reductions are expected due to implementation of best-practice technologies, but on the other, the switch to unconventional sources increases energy intensity (IPCC, 2014c). All these uncertainties mainly cause these sectors to be largely neglected by GHG scenarios and that including these sectors in the SITA methodology is not yet possible.

Similar uncertainties exist for the agricultural sector. Although this sector is responsible for 10 to 12% of global GHG emissions, only very recently (May 2014) WRI presented the first agricultural guidance for agricultural companies to measure, manage and report their GHG emissions (IPCC, 2014c; WRI, 2014). Only 25% of the agricultural producers that are targeted by CDP disclose their emissions. Perhaps this guidance results in more companies measuring and reporting their GHG emissions. More emissions data for this sector could result in better scenarios and possibly eventual inclusion in the SITA method.

The waste sector is not included for several reasons. First, the waste sector is very heterogeneous. A company that handles municipal solid waste is not easily compared to a company that handles chemical waste. Second, waste companies often have more than one useful output. A company that recycles waste can have plastic, glass, metals, and even electricity and heat as useful outputs. Third, an intensity target does not capture the most efficient abatement measures in the waste sector: waste prevention, re-use, and recycling (IPCC, 2014c). An efficient way to set targets for the waste sector might be to make companies responsible for their products' end-of life (scope 3) GHG emissions. Unfortunately, this is not yet possible due to a lack of reporting and measuring standards.

Structural differences within sectors

Although the SITA sectors are selected on their homogeneity, structural differences can result in targets that are more difficult to meet for certain companies than for others. For example, ore quality has a significant impact on the emissions intensity for iron (IEA, 2012a). It is possible to determine factors that can be applied to the sectoral pathways to account for such structural differences. Furthermore, differences in national emission factors of purchased electricity can have a major impact on a company's scope 2 emissions. This incentivises companies to relocate to a country where the electricity is less carbon-intensive, and thereby gives governments incentives to stimulate decarbonisation of their national electricity supply. However, this is not entirely fair because of geographical factors like potential for wind, solar, and hydro. This problem can also be accounted for with geographical factors for electricity, but requires further research.

Geographical discrimination

The SITA methodology sets targets for companies independent of their geographical location. This is the result of using the contraction and convergence principle. By converging the emission intensity, developing countries are allowed to grow, as long as they do so in a responsible way, with their intensity decreasing to the 2050 target. This convergence is not conform to the burden sharing principles of the UNFCCC. However, since the SITA method focusses on voluntary climate action by companies, these burden-sharing unconformities are not directly relevant. However, the geographical differences between countries and regions (e.g. potential for renewables or ore quality) are relevant for companies, and not accounted for in the SITA method. These differences can be accounted for when a more detailed scenario is available. However, that would increase the data requirement for the company and the complexity of the method.

Scope 3 emissions

The SITA method as presented in this thesis only sets one very specific scope 3 target for manufacturers of light road passenger transport vehicles. This means that the SITA method does not set a scope 3 emission target for most companies. Scope 3 targets overlap other companies' or consumers' scope 1 target. If it overlaps another companies' scope 1 emissions, scope 3 targets results in an extra incentive for a company. However, this incentive can be placed somewhere else along the supply chain. For example, a car manufacturer can set a scope 3 target to reduce its emissions, or a car rental service sets a scope 1 target for its fleet. If sufficient car rental services set scope 1 targets, the car manufacturer will be incentivized to produce less emission intensive cars. However, consumers are not likely to set a SITA target, so for the emissions arising from consumption of a good, scope 3 targets are necessary. With additional research, it might be possible to create more scope 3 targets in line with the 2DS scenario.

Non-CO_2 greenhouse-gases

The 2DS scenario only focusses on CO_2 emissions, thereby neglecting a large share (35% on CO_2e basis) of GHG emissions. ETP2012 states that in order to reach the 2 °C target, deep cuts in emissions of non-CO_2 GHGs are required besides the CO_2 emission abatement described in their report (IEA, 2012a). Considering that the CO_2 emission pathway of 2DS is similar to that of RCP2.6 (Schaeffer & van Vuuren, 2012), the emission pathways of the other gases should be similar to those described by van Vuuren, Stehfest et al. (2011). However, the allocation of these emissions to sectors is not possible because of a lack of sectoral detail in the model.

Complexity

Because of the different approaches for different sectors, multiple allocation steps, and relatively complex convergence (as described in section 2.2.6.) to the sectoral intensity pathway, the SITA method is relatively complex, when compared to the other methods mentioned in chapter 3. However, this was expected when looking at the emission intensity indicator pyramid in Figure 3. Solving the problems described above will most likely result in an even more complex SITA method. This complexity might cause companies to decide not to implement the targets. However, if such a complex approach is backed by sufficient governments, NGOs and institutions, companies might be incentivised to implement it anyway.

Use of value added (VA) as activity indicator

VA is not the ideal activity indicator. First, company VA is not always publicly available. Second, VA does not correlate strongly with GHG emissions. Third, VA fluctuates, thereby influencing targets. However, when a sector is homogeneous, no better alternative is available. A solution might be to further disaggregate or account for structural differences, but that would require significantly more data and would make the method more complex. Another option is for policymakers to implement disclosure policies for VA data.

Lack of conformity with existing policies

The SITA method results in targets that are not in line in what is necessary to meet climate policies such as the European Union’s Emissions Trading Scheme (EU ETS). Although the EU ETS also allocates a large share of emission reductions on a low-cost basis, there is a significant difference in the distribution due to free emissions allocation. The EU ETS freely allocates emissions to certain emission-intensive sectors (such as the manufacturing industries or the aviation sector), in order to allow them to adapt(European Commission, 2013). Although there are reasons behind this free allocation (mostly competitiveness-at-risk concerns), it results in emission abatements that are not least-cost optimized. Furthermore, the EU ETS focusses on individual installations and operates on an absolute-basis. The SITA method operates on an intensity-basis and targets sectors instead of individual installations. The largest difference between SITA target and policy requirements is in the industrial sectors. However, the SITA targets are not meant for companies that want to ensure compliance, but for the companies that want to do their fair share to avert catastrophic climate change. For that purpose, existing policies (such as the EU ETS) fall short (Ecofys, Climate Analytics, & Potsdam Institute for Climate Impact Research, 2013).

8.3. Suggestions for further research

Most of the limitations to the SITA method as presented in this thesis (i.e. based on the 2DS from ETP2014) are due to data limitations. Including more sectors in the scenario would improve the methodology and set more specific targets. Further disaggregation of sectors is possible by breaking up sectors into their different technologies and setting even more specific targets. For most energy-intensive industries, benchmark approaches have been developed that offer such bottom-up detail. However, these approaches are generally not publicly available, mostly based on proprietary data, and complex. Further research could focus on using publicly available data to estimate parameters that account for structural differences within these sectors.

Recently (June 2014), the IPCC AR5 scenarios database was made available to the public (International Institute of Applied System Analysis, 2014). This database comprises 31 IAMs and in total 1,184 mitigation scenarios. Future studies could assess the possibility of using the 2 °C scenarios in this database to distil sectoral pathways that truly represent the scientific consensus. Furthermore, this database might enable inclusion of more GHGs in the SITA method.

Data required for the construction of scope 3 pathways is often not available. Future studies looking into scope 3 emissions and how they correlate with, for example, number of employees could help fill this knowledge gap. Also, the development of clear scope 3 reporting standards would allow for better scope 3 target-setting. Furthermore, existing scenario data could be assessed in order to identify whether more scope 3 pathways can be distilled from it.

In this thesis, the intensity pathways are constructed by linearly reducing the difference between the company pathway and sector average. However, this method of convergence might not be optimal and is chosen rather arbitrarily. A study investigating the effects of using different converging methods (e.g. converging with a constant percentage, or based on feasibility) could improve the method quality.

Although there is a need for further research to improve the SITA method, and complement it by including the remaining sectors, this thesis has taken a significant step in exploring this novel method of attributing GHG emissions to individual companies.

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9. Conclusion

In accordance with the main research question, this thesis developed a sectoral approach to corporate GHG emission target-setting. The resulting sectoral intensity target approach (SITA) adds to existing literature and target-setting methods by stepping down in the emission intensity indicator pyramid (Figure 3) and thereby increasing the correlation of the activity with the GHG emissions. Using this method, the sectoral emissions budget is allocated to the companies in that sector in a way that is fairer than that of other methods (such as allocation to share of profits). SITA targets are primarily intensity targets, but can be converted into absolute targets by estimating activity growth. SITA targets can be verified by third parties because SITA is based on publicly available data.

The SITA version based on IEA's 2DS (IEA, 2014), as developed in this thesis, sets CO_2 emissions targets for 13 sectors. It covers mostly scope 1 and scope 2 emissions, but also scope 3 emissions from light road vehicle use. The method covers 84% of 2010 CO_2 emissions arising from fossil fuel combustion and industrial processes. The most energy-intensive companies are covered, thereby increasing the potential impact of the method. If all companies followed the intensity pathways prescribed by the SITA methodology, their combined CO_2 emissions would be reduced with 57% from 2011 to 2050. This is in line with the target of limiting global warming to 2 °C.

By selecting a scenario to calculate sectoral intensity targets, and testing the SITA methodology on case studies, this thesis shows the advantage of the sectoral intensity approach, compared to the other methods found in the literature review. However, this thesis is only the first step. Several companies are currently considering implementation of SITA targets, and NGOs WWF and WRI are planning to actively promote this method and to get more large companies to implement science-based CO_2 emission targets. The lessons learned in setting SITA targets for these pioneering companies can be of great value for further development of the SITA methodology. Furthermore, improving the SITA methodology can help these NGOs to encourage companies to take voluntary climate action. Further research on SITA target-setting should be focussed on covering all companies and GHGs, and investigating the possibility of using combined scenarios as the SITA input.

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Appendices

Appendix A: List of abbreviations and acronyms

2DS	IEA's two degrees scenario described in ETP
AR	assessment report
BAU	business-as-usual
BECCS	bioenergy carbon capture and storage
BT	British Telecom
CAGR	Compound average annual growth rate
CCS	carbon capture and storage
CDP	Carbon Disclosure Project
C-FACT	corporate finance approach to climate-stabilizing targets
CH_4	methane
CHP	combined heat and power
CO_2	carbon dioxide
CO2e	CO2 equivalent
CSI	climate stabilization intensity
CSO	Center for Sustainable Organizations
E[R]	Energy [R]evolution
EAF	electric arc furnace
EFOM	energy flow optimization model
EIT	European Institute for Innovation and Technology
EPA	Environmental Protection Agency
ETP	energy technology perspectives
EU	European Union
FTE	fulltime-equivalent
GDP	gross domestic product
GEVA	greenhouse-gas emissions per value added
GHG	greenhouse-gas
GICS	Global Industry Classification Standard
IAM	integrated assessment model
ICT	information and communications technology
IEA	International Energy Agency
IMAGE	integrated model to assess the global environment
IPCC	Intergovernmental Panel on Climate Change
kg	kilogram
KIC	Knowledge and Innovation Community
kWh	kilowatt hour
LIMITS	low climate impact scenarios and the implications of required tight emissions control strategies
MAC	marginal abatement costs
MARKAL	market allocation
MCA	multi-criteria analysis
MESAP	modular energy system analysis and planning environment

MoMo	mobility model
NGO	non-governmental organization
OECD	Organization for Economic Co-operation and Development
PD	peak-and-decline
pkm	person kilometer
PlaNet	planning network
ppm	parts per million
ppmv	parts per million by volume
R&D	research and development
RCP	representative concentration pathway
SITA	Sectoral Intensity Target Approach
SRES	special report emissions scenarios
SRREN	special report on renewable energy sources and climate change mitigation
TES	the energy scenario
TIMER	targets image energy regional
TIMES	the integrated MARKAL-EFOM system
TTW	tank-to-wheel
TWh	Terrawatt-hour (10^9 kWh)
U.K.	United Kingdom
U.S.	United States of America
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
VA	value added
vkm	vehicle kilometer
WBCSD	World Business Council for Sustainable Development
WEO	World Energy Outlook
WRI	World Resources Institute
WTW	well-to-wheel
WWF	World Wide Fund for Nature

Appendix B: List of figures and tables

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Appendix C: Compound annual growth rate calculation

The compound annual growth rate is the percentage year-on-year annual growth that results in a certain growth over multiple years. It is calculated using:

$$CAGR(t_a, t_b) = \left(\frac{V(t_b)}{V(t_a)}\right)^{\frac{1}{t_b - t_a}} - 1 \qquad \text{(Equation 2)}$$

Where:

CAGR = Compound annual growth rate calculation
$V(t_a)$ = start value
$V(t_b)$ = end value
t_b-t_a = years between start value and end value

Appendix D: Sector definitions and boundaries

The sectors for which sectoral CO_2 emissions pathways are determined are given in Table 11 with a description of the companies in the sectors. Also, the classification of the chosen sectors in the Global Industry Classification Standard (GICS) are given in the table (Standard & Poor's & MSCI Barra, 2008). The other industry and service buildings sectors are not defined using GICS sectors.

Table 11: SITA sectors and GICS definition.

Sector	GICS sectors	Description
Power generation	Utilities (55) excluding Gas Utilities (551020)and Water Utilities (551040)	Companies that generate and sell electricity.
Cement	Construction Materials (15102010) excluding manufacturers of sand, clay, gypsum, lime, aggregates, and bricks	Manufacturers of cement.
Iron and Steel	Steel (15104050)	Producers of iron and steel and related products, including metallurgical (coking) coal mining used for steel production.
Pulp and paper	Paper products (15105020) Paper packaging (15103020) and paper product producing companies in Houshold products (30301010)	Producers of paper and paperboard products.
Aluminium	Aluminium (15104010)	Producers of aluminum and related products, including companies that mine or process bauxite and companies that recycle aluminum to produce finished or semi-finished products.
Chemicals and petrochemicals	Chemicals (151010)	Companies that primarily produce chemical products
Other industry	Other manufacturing industries not included in other sectors	
Aviation passenger transport	Airlines (203020)	Companies that have air transport of passengers as their core business.
Light road passenger transport	Passenger transport in the Trucking (20304020) sector using vehicles that weigh under 4,500 kg	Companies providing primarily passenger land transportation. Includes vehicle rental and taxi companies.
Heavy road passenger transport	Passenger transport in the Trucking (20304020) sector using vehicles that weigh above 4,500 kg	Companies providing primarily passenger land transportation. Includes bus travel companies.
Rail passenger transport	Passenger transport in the Railroads (20304010) sector	Companies providing primarily passenger rail transportation.
Service buildings	All companies of which most of their CO2 emissions arise from their buildings	
Light road passenger vehicles	Automobile manufacturers (25102010)	Companies that produce mainly passenger automobiles and light trucks. Excludes companies producing mainly motorcycles and three-wheelers and heavy duty trucks.

Appendix E: Scenario source quality analysis

Figure 40 shows the amount of references to peer-reviewed literature for each scenario both in absolute amount as a percentage of total references. For every scenario, except for E[R], the list of references is assessed.

The E[R] report did not have a list of references, but instead used footnotes to refer to sources. These footnotes were given a number (up to 184), but this number could not be used as the total number of references, because some in-text references were not given a footnote, and some footnotes were referring to the same source, resulting in double counting. On top of that, the references only stated the author name and the year, so not the title of the article or the name of the journal. Therefore, the E[R] report is assessed based on a random selection of 54 citations, for each of which the source was looked up, and of which 2 sources were peer-reviewed scientific articles.

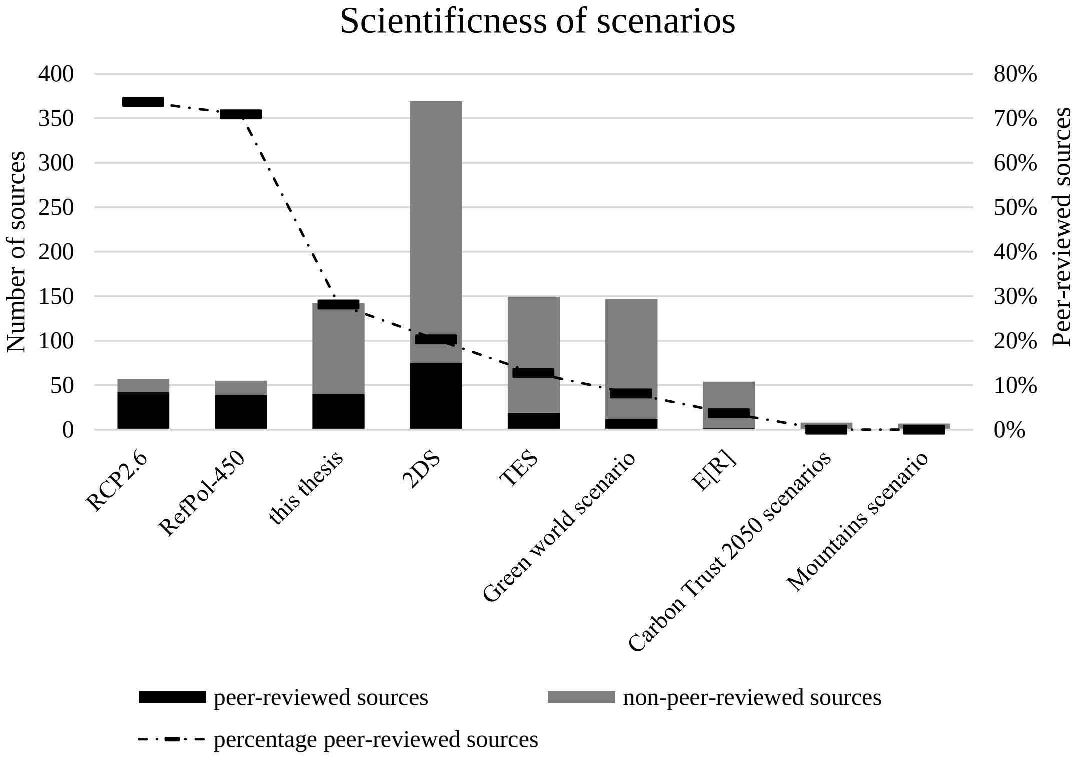

Figure 40: Source quality assessment of scenarios and this thesis for reference.

Appendix F: Case study data sources

Sector	Company	Input	2010	2011	2012	2013	Source(s)
Power Generation	EDF	Scope 1 CO_2 emissions ($ktCO_2$)	80,576	70,936	80,284		(CDP, 2011, 2012, 2013a)
		Activity (TWh)	630	628	643		(EDF, 2010, 2011, 2012)
	CLP	Scope 1 CO_2 emissions ($ktCO_2$)	41,649	44,260	38,245		(CDP, 2011, 2012, 2013a)
		Activity (TWh)	55	49	50	50	(CLP, 2010, 2011, 2012, 2013)
Iron and steel	ArcelorMittal	Scope 1 CO_2 emissions ($ktCO_2$)	165,226	162,028	158,192		(CDP, 2011, 2012, 2013a)
		Scope 2 CO_2 emissions ($ktCO_2$)	19,599	17,902	17,256		(CDP, 2011, 2012, 2013a)
		Activity (kt crude steel)	90,600	91,891	88,200	91,200	(ArcelorMittal, 2011, 2013)
	POSCO	Scope 1 CO_2 emissions ($ktCO_2$)	68,705	74,602	73,525		(CDP, 2011, 2012, 2013a)
		Scope 2 CO_2 emissions ($ktCO_2$)	2,974	3,625	3,471		(CDP, 2011, 2012, 2013a)
		Activity (kt crude steel)	33,716	37,325			(POSCO, 2010, 2011)
Automotive	Daimler	Scope 1 CO_2 emissions ($ktCO_2$)	1,064	1,016	960		(CDP, 2011, 2012, 2013a)
		Scope 2 CO_2 emissions ($ktCO_2$)	2,635	2,503	2,331		(CDP, 2011, 2012, 2013a)
		Activity ($M€_{2010}VA$)	2,773	3,641	4,094	5,528	(Daimler, 2011a, 2013a)
		Vehicle CO2 intensity (gCO_2/vkm)	158	150	140	134	(Daimler, 2011b, 2013b)
	Volkswagen	Scope 1 CO_2 emissions ($ktCO_2$)	1,287		4,134		(CDP, 2011, 2012, 2013a)
		Scope 2 CO_2 emissions ($ktCO_2$)	6,307		4,572		(CDP, 2011, 2012, 2013a)
		Activity ($M€_{2010}VA$)	32,922	46,625	56,804	44,998	(Volkswagen, 2010, 2011, 2012, 2013a)
		Vehicle CO_2 intensity (gCO_2/vkm)	144	137	134	128	(Volkswagen, 2013b)

Appendix G: ETP2012 sectoral CO_2 emission intensity pathways

Table 12 shows the sectoral CO_2 emission intensity pathways that are constructed based on IEA’s 2DS scenario from ETP2012.

Table 12: Sectoral pathways according to IEA's 2012 2DS scenario.

Sector	Intensity indicator	Scope	2010	2015	2020	2025	2030	2035	2040	2045	2050
Power generation	gCO2/kWh	1	575.75	515.69	469.94	345.64	230.82	146.01	95.53	74.35	56.57
Cement	tCO2/t cement	1	0.70	0.63	0.54	0.52	0.51	0.49	0.45	0.42	0.38
	tCO2/t cement	2	0.06	0.05	0.04	0.03	0.02	0.01	0.01	0.01	0.01
Iron and steel	tCO2/t crude steel	1	1.79	1.52	1.29	1.19	1.07	0.96	0.85	0.76	0.67
	tCO2/t crude steel	2	0.38	0.33	0.29	0.22	0.15	0.10	0.06	0.05	0.04
Pulp and paper	tCO2/t paper and cardboard	1	0.56	0.46	0.39	0.32	0.27	0.23	0.20	0.18	0.16
	tCO2/t paper and cardboard	2	0.73	0.60	0.51	0.35	0.22	0.13	0.08	0.06	0.04
Aluminium	tCO2/t aluminium	1	2.64	2.42	2.31	2.24	2.20	2.06	1.91	1.76	1.62
	tCO2/t aluminium	2	5.51	4.52	3.88	2.69	1.73	1.02	0.62	0.45	0.32
Automotive use	gCO2/pkm	3	176.85	156.77	140.48	116.46	88.21	75.58	68.15	67.63	67.11
Aviation	gCO2/pkm	1	151.69	124.90	106.62	88.42	74.15	60.19	53.74	49.21	45.87
Commercial buildings	kgCO2/m2	1	24.35	22.12	20.21	18.57	17.14	15.88	14.76	13.76	12.87
	kgCO2/m2	2	66.10	58.63	52.98	39.05	26.07	16.38	10.62	8.24	6.12
Chemicals and petrochemicals	2010=100%	1	100%	77%	66%	56%	47%	39%	33%	27%	22%
	2010=100%	2	100%	84%	71%	46%	27%	14%	8%	5%	4%
Other industry	2010=100%	1	100%	84%	71%	55%	41%	31%	28%	26%	23%
	2010=100%	2	100%	94%	85%	56%	34%	19%	11%	8%	6%
Other transport	2010=100%	1	100%	82%	68%	59%	51%	42%	34%	28%	23%
	2010=100%	2	100%	95%	87%	75%	59%	45%	34%	28%	22%

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