Greenhouse gas emission reductions enabled by products from the chemical industry

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By: Edgar van de Brug, Annemarie Kerkhof, Maarten Neelis and Wouter Terlouw

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Foreword

The chemical industry plays an essential role in enabling other industries to improve their energy efficiency and reduce their greenhouse gas emissions (GHG). This is achieved by using chemical products and technologies. Several ICCA reports have underpinned the scale of the chemical industry's contribution to enabling emissions reduction, also known as "avoided emissions". "*Innovation for Greenhouse Gas Reductions: A life cycle quantification of carbon abatement solutions enabled by the chemical industry*" (2009) and "*ICCA Building Technology Roadmap: The Chemical Industry's Contribution to Energy and Greenhouse Gas Savings in Residential and Commercial Construction*" (2013) are the most relevant examples.

Subsequently, to improve consistency in the assessment and reporting of avoided emissions, ICCA and WBCSD published a practical guidance document entitled "*Addressing the Avoided Emissions Challenge*" (2013).

Building on the past work, ICCA conducted a new study on the maximum potential for annual GHG emissions reduction enabled by the chemical industry for selected six solutions in a specific year. Moreover, a scenario analysis on annual GHG emissions reduction enabled by the chemical industry for selected six solutions in 2030 is being prepared.

The objective of this study is to assess the global contribution of the chemical industry to selected six solutions in the context of limiting average temperature rise to 2 degrees Celsius, as agreed on in the Paris Agreement in 2015. Despite the small number of solutions considered, the magnitude of chemical products' contribution is remarkable. The study on the maximum potential indicates that even a higher reduction seems feasible in 2030 with appropriate and enabling policies in place.

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Summary

- The Paris Agreement confirmed the need for keeping global warming to "well below 2 degrees Celsius" by the end of the century. In the Synthesis Report by the United Nations Framework Convention on Climate Change (UNFCCC), it is stated that current greenhouse gas (GHG) emissions reductions pledges made by 189 developed and developing countries would necessitate greater and more costly emission reductions after 2030 to achieve this goal, as compared to the least cost scenario. Therefore, a higher level of GHG emissions reduction in all countries and all sectors is deemed necessary in the first half of the century.
- The chemical industry contributes to many solutions that increase the energy efficiency in multiple sectors and contribute to an increase of renewable energy supply, thereby reducing and avoiding emissions in many value chains.
- This study focuses on six important solutions to which the chemical industry contributes: wind and solar power, efficient building envelopes, efficient lighting, electric cars, fuel efficient tires and lightweight materials. Another important application, food packaging, is also discussed using a different methodology, due to concerns about data quality.
- This study shows that global emissions would be over 9 $GtCO_2e$ per year lower if the selected six solutions were used to their full potential right now; this exceeds the annual emissions of the United States.[1]
- Using a different approach, this study also quantifies the emission reduction of the selected solutions in 2030 in a mitigation scenario (limiting temperature increase to 2 degrees Celsius) as compared to a reference scenario. The study shows that the selected six solutions reduce emissions by 2.5 $GtCO_2e$ as compared to the reference.[2] This is equivalent to the annual emissions of France, Germany, Italy and the United Kingdom together.[3]
- The chemical industry has the potential to contribute even more than the selected six solutions and to further accelerate its contribution also beyond the 2030 timeframe. For each solution to reach its full potential, joint action from all partners in the value chain is a critical success factor.
- To achieve the potential of GHG reductions, different business models supported by enabling policy conditions are required. Such enabling policies should foster cost effective solutions based on a life-cycle approach while harnessing all viable energy sources integrated into normal market conditions.

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[1] Annual emissions of the United States were 6.3 $GtCO_2e$ in 2012 according to http://edgar.jrc.ec.europa.eu/

[2] It should be noted the use of some of the chemical solutions will increase also in the reference scenario in 2030 as compared to the situation nowadays. Part of the 9 $GtCO_2e$ potential identified following the first approach will thus also already be tapped in the reference scenario.

[3] The emissions of France, Germany, Italy and the United Kingdom were 2.5 $GtCO_2e$ in 2012 according to http://edgar.jrc.ec.europa.eu/.

Context, project goal and approach

"The International Council of Chemical Associations (ICCA) firmly supports the UN Framework Convention on Climate Change (UNFCCC) and welcomes its successful outcome during the 21st meeting of the Conference of the Parties (COP21). The Paris Agreement is an important framework for international cooperative action that reflects strong political commitment by all economies to the measurement, monitoring and reporting of nationally determined contributions to reduce greenhouse gas (GHG) emissions." [4]

The Paris Agreement confirmed the need for higher level of GHG emissions reduction in all countries and all sectors in the coming century. In the IPCC Climate Change 2014 Synthesis report it is stated that "many adaptation and mitigation options can help address climate change, but no single option is sufficient by itself. Effective implementation depends on policies and cooperation at all scales (…)".[5] The chemical industry is part of the life cycle of many everyday products. This unique position offers the chemical industry opportunities to reduce GHG emissions throughout all parts of society.

In this report six representative solutions have been selected and studied. The chemical industry contributes to the value chain emission reductions these solutions enable: wind and solar power, efficient building envelopes, efficient lighting, electric cars, fuel efficient tires and lightweight materials. A seventh important solution, the use of packaging material to reduce food losses, is also commented on using a different methodology, due to concerns about data quality.

These solutions improve energy efficiency or contribute to an increase of renewable energy supply. The solutions represent an important share of the emission reductions enabled by contributions of the chemical industry, but there are more solutions in other sectors as well. While the chemical industry contributes extensively to these solutions, their contribution occurs alongside contributions from other enabling parties in the value chain.

ICCA has been actively involved for years in efforts to quantify the potential for the value chain emission reductions in a fact-based and transparent way. In terms of the method used, this report builds on these studies including the innovations for GHG reductions study, the avoided emission guidelines, and the case studies to showcase the application of the these guidelines.[6,7,8] Two distinct approaches are used in this study to quantify the emission reductions enabled by the chemical industry:

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[4] Taken from ICCA views on COP21, February 2016

[5] IPCC, 2014. Climate Change 2014 Synthesis Report. Synthesis report of the IPCC Fifth Assessment Report (AR5) available at: https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_All_Topics.pdf.

[6] ICCA, 2009. *Innovations for Greenhouse Gas Reductions: A life cycle quantification of carbon abatement solutions enables by the chemical industry.* Available at: http://www.icca-chem.org/ICCADocs/ICCA_A4_LR.pdf.

[7] ICCA, 2013. Addressing the Avoided Emissions Challenge: Guidelines from the chemical industry for accounting for and reporting greenhouse gas (GHG) emissions avoided along the value chain based on comparative studies. Available at: http://www.icca-chem.org/iccadocs/E%20CC%20LG%20guidance_FINAL_07-10-2013.pdf.

[8] ICCA, 2016. Reduction of Greenhouse Gas Emissions via Use of Chemical Products – Case studies: Exemplifying the application of the ICCA & WBCSD Avoided Emissions Guidelines.

1. **Approach I: Estimated annual emission reductions if the solutions were used to their full potential right now.** In this approach, it is estimated how much higher emissions would be if the solutions were not used at all (zero market share versus current market share) and how much lower emissions would be if the solutions were used to their full potential right now (up to 100% market share).

2. **Approach II: Contribution of the solutions to the GHG emission reductions in 2030 in a 2 degrees Celsius mitigation scenario as compared to a reference scenario.** In this approach, it is estimated what the contribution of the solutions is to emission reductions in a mitigation scenario (limiting temperature increase to 2 degrees Celsius) as compared to a reference scenario. The scenarios are based on the IEA Energy Technology Perspectives 2015 (IEA ETP 2015) scenarios. The reference scenario is based on the 6DS scenario and the mitigation scenario is based on the 2DS scenario. Assumptions not specified in IEA ETP 2015 are determined by expert judgement.

The results from the different approaches are not directly comparable, but both provide insights in the potential GHG emissions reduction enabled by the solutions to which the chemical industry contributes.[9] The study also addresses the enabling conditions (business and policies related) needed to realise this potential along the value chains.

Main results

Figure 1A shows that the global annual emissions would be over 9 $GtCO_2e$ lower if the selected solutions were used to their full potential right now. For comparison, this is substantially more than the current annual emissions of the United States.[1] Renewable energy (solar and wind power) as well as energy efficiency measures (such as electric cars, efficient building envelopes and efficient lighting) are major contributors to this potential.

Figure 1B shows that the selected solutions reduce emissions by 2.5 $GtCO_2e$ in 2030 in a 2 degrees Celsius mitigation scenario as compared to a reference scenario. This is equivalent to the annual emissions of France, Germany, Italy and the United Kingdom together.[3] The relative contribution of each of the solutions is comparable to the results obtained using the first approach.

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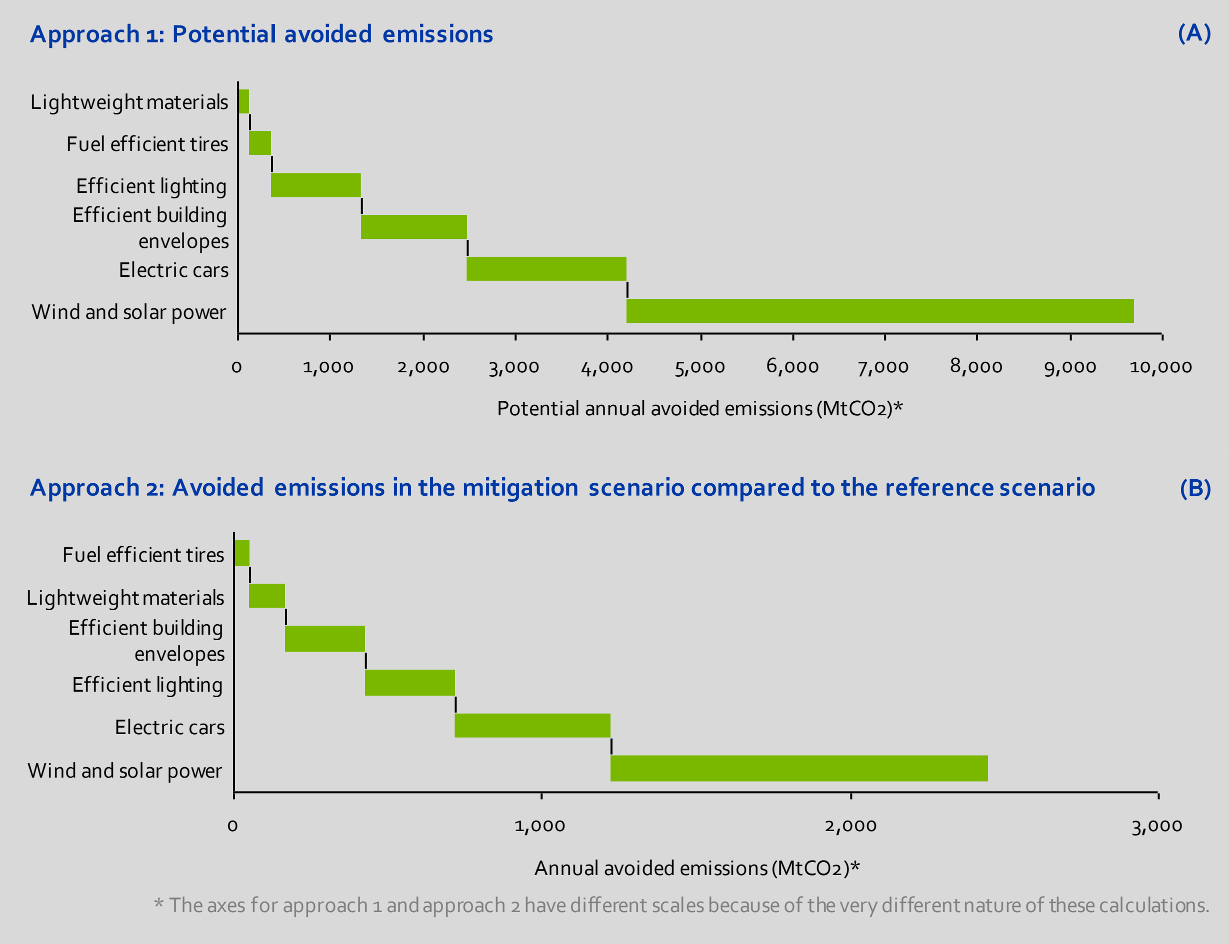
[9] The first approach investigates the potential at this moment in time, the second approach looks into the situation in 2030. Also, the use of some of the chemical solutions will increase also in the reference scenario in 2030 as compared to the situation nowadays. Part of the potential identified following the first approach will thus also already be tapped in the reference scenario.



Approach 1: Potential avoided emissions (A)

Approach 2: Avoided emissions in the mitigation scenario compared to the reference scenario (B)

* The axes for approach 1 and approach 2 have different scales because of the very different nature of these calculations.

Figure 1. (A) Result of approach 1: Estimated annual emission reduction if the solutions were used to their full potential right now; (B) Result of approach 2: Contribution of the solutions to the GHG emission reductions in 2030 in a 2 degrees Celsius mitigation scenario as compared to a reference scenario.

Enabling conditions and concluding remarks

Many industrial and other stakeholders work together for each of the studied solutions. Enhanced value chain cooperation is needed to fully exploit the potential. The chemical industry is, for example, committed to providing energy efficient solutions to the buildings sector, by efforts such as participation in pilot projects, sponsoring life cycle assessment studies, investments in research and development, and cooperation with the value chain; from architects to craftsmen.[10]

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[10] *ICCA, 2015. ICCA Building Technology Roadmap: The Chemical Industry's Contributions to Energy and Greenhouse Gas Savings in Residential and Commercial Construction.* Executive summary available at: https://www.icca-chem.org/wp-content/uploads/2015/08/ICCA-Building-Technology-Roadmap-Executive-Summary.pdf.

An enabling policy environment is needed, stimulating greenhouse gas emission reductions along the full value chain, including use and end-of life phases.

- Governments should establish technology neutral policies which enable cost effective **renewable energy** to grow and contribute to greenhouse gas emission reductions, while ensuring the reliable, affordable, and non-intermittent supply of electricity. Financial support should only be available for technology development of pre-commercial innovative technologies. All technologies should be integrated into normal market conditions, removing subsidies as soon as the technology is commercial.

- **Energy efficient** measures have a large potential of saving energy and reducing greenhouse gas emissions worldwide. Governments should, for example, set energy efficiency standards, encourage manufacturers to provide correct and easy-to-understand information, and take necessary actions to raise public awareness depending on regional/national circumstances.

Further work is needed, also by the modelling teams, to shed more light on the exact impact mitigation will have on the material demand and resulting emissions of the chemical industry itself; a somewhat unexplored issue in the current modelling due to the focus on the use phase of emissions in the scenario work.

The selected solutions highlight the opportunities of the chemical industry in a low carbon world. The chemical industry has the potential to contribute even more and to further accelerate its contribution also beyond the 2030 timeframe. For all solutions to be used widely, joint action from all partners in the value chain is needed, as well as different business models, supported by sufficiently enabling policy conditions at an adequate level.

Table of contents

1 Introduction

The Paris Agreement confirmed the need for keeping global warming to "well below 2 degrees Celsius" by the end of the century. In the Synthesis Report by the United Nations Framework Convention on Climate Change (UNFCCC), it is stated that current greenhouse gas (GHG) emissions reductions pledges made by 189 developed and developing countries would necessitate greater and more costly emission reductions after 2030 to achieve this goal, as compared to the least cost scenario. Therefore, a higher level of GHG emissions reduction in all countries and all sectors is deemed necessary in the first half of the century. In the *"Climate Change 2014 Synthesis Report"* it is stated that "many adaptation and mitigation options can help address climate change, but no single option is sufficient by itself. Effective implementation depends on policies and cooperation at all scales (…)".[11]

The International Council of Chemical Associations (ICCA) firmly supports the UNFCCC. It welcomes the Paris Agreement as an important framework for international cooperative action that reflects strong political commitment by all economies to the measurement, monitoring and reporting of nationally determined contributions to reduce GHG emissions.

The chemical industry is a significant emitter of GHG emissions and is committed to reduce these emissions via a wide range of mitigation activities. At the same time, many innovative chemical industry products enable GHG emission reductions downstream in the value chain, also referred to as avoided emissions, e.g. lightweight materials in cars to save fuels and insulation materials to save energy for heating buildings. In this way, the chemical industry contributes to GHG emission reductions throughout society and enables a low carbon world.[12]

Reliable and credible figures on GHG emission reductions enabled by solutions with chemical products are essential to demonstrate the potential contribution of the chemical industry to future emission reductions and to provide context for the development of the chemical industry's own emissions under a mitigation scenario. ICCA has been actively involved for years in efforts to quantify this potential in a fact-based and transparent way.

This report builds on the previous work done by ICCA. In 2009, the study "*Innovations for Greenhouse Gas Reductions: A life cycle quantification of carbon abatement solutions enabled by the chemical industry*" was published, providing comparisons between numerous chemical products with their next

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[11] IPCC, 2014. *Climate Change 2014 Synthesis Report.* Synthesis report of the IPCC Fifth Assessment Report (AR5) available at: https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_All_Topics.pdf.

[12] With the term "low carbon world", we mean a world economy that functions well without excessive emissions of greenhouse gases like carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and F-gases (hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3)).

best non-chemical alternatives.[13] This publication was followed by guidelines on assessing avoided emissions, "*Addressing the Avoided Emissions Challenge",* developed in 2013 by ICCA, together with the WBCSD, and with support of Ecofys.[14] The guidelines include clear requirements on how to define the functional unit, choose the baseline and how to deal with attribution of avoided emissions along the value chain. The use of such sector-wide guidelines increases the consistency of calculations and the credibility of communicated emission reductions. To show the use of the guidelines, case examples were published in the report "*Reduction of Greenhouse Gas Emissions via Use of Chemical Products – Case studies*" and on the ICCA website.[15,16]

Innovations for Greenhouse Gas Reductions

A life cycle quantification of carbon abatement solutions enabled by the chemical industry

July, 2009

Addressing the Avoided Emissions Challenge

Guidelines from the chemical industry for accounting for and reporting greenhouse gas (GHG) emissions avoided along the value chain based on comparative studies

October 2013

ICCA - Worldwide Voice of the Chemical Industry

Reduction of Greenhouse Gas Emissions via Use of Chemical Products

Case Studies

Exemplifying the Application of the ICCA & WBCSD Avoided Emissions Guidelines

2009 **2013** **2016**

Figure 2. Overview of initiatives on avoided emissions in the chemical industry.

Given that the 2009 estimates of global avoided emission reduction are now outdated and that since then, methodological progress has been made, ICCA wants to update the avoided emission estimates. In this study seven important solutions to which the chemical industry fundamentally or extensively contributes, are studied:

- Wind and solar power
- Efficient building envelopes
- Efficient lighting
- Electric cars
- Fuel efficient tires
- Lightweight materials
- Packaging

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[13] ICCA, 2009. *Innovations for Greenhouse Gas Reductions: A life cycle quantification of carbon abatement solutions enables by the chemical industry.* Available at: http://www.icca-chem.org/ICCADocs/ICCA_A4_LR.pdf.

[14] ICCA/WBCSD, 2013. *Addressing the Avoided Emissions Challenge: Guidelines from the chemical industry for accounting for and reporting greenhouse gas (GHG) emissions avoided along the value chain based on comparative studies.* Available at: http://www.icca-chem.org/iccadocs/E%20CC%20LG%20guidance_FINAL_07-10-2013.pdf.

[15] ICCA, 2016. *Reduction of Greenhouse Gas Emissions via Use of Chemical Products – Case studies: Exemplifying the application of the ICCA & WBCSD Avoided Emissions Guidelines.*

[16] Available at: https://www.icca-chem.org/energy-climate/.

The selected solutions help to improve energy efficiency or to contribute to an increase of renewable energy supply. The solutions represent the lion share of the emission reductions enabled by contributions of the chemical industry, but there are more solutions in other sectors as well.[13] While the chemical industry contributes extensively to these solutions, their contribution occurs alongside contributions from other enabling parties in the value chain.

To illustrate the contribution of the chemical industry in enabling avoided emissions, two distinct approaches are used:

1. **Approach I: Estimated annual emission reductions if the solutions were used to their full potential right now.** In this approach, it is estimated how much higher emissions would be if the solutions were not used at all (zero market share versus current market share) and how much lower emissions would be if the solutions were used to their full potential right now (up to 100% market share).

2. **Approach II: Contribution of the solutions to the GHG emission reductions in 2030 in a 2 degrees Celsius mitigation scenario as compared to a reference scenario.** In this approach, it is estimated what the contribution of the solutions is in to emission reductions in a mitigation scenario (limiting temperature increase to 2 degrees Celsius) as compared to a reference scenario. The scenarios are based on the IEA Energy Technology Perspectives 2015 (IEA ETP 2015) scenarios. The reference scenario is based on the 6DS scenario and the mitigation scenario is based on the 2DS scenario. Assumptions not specified in IEA ETP 2015 are determined by expert judgement.

Finally, this report addresses the enabling conditions that are needed to realise this potential in practice. This information can help stakeholders, like chemical industry value chain partners and national policy-makers worldwide, to take measures to reduce GHG emissions and therefore contribute to achieving the ambitions agreed upon at the COP21 in Paris and the related Nationally Determined Contributions (NDCs).

2 Approach

2.1 Methodological background

The goal of this study is to obtain fact-based figures on avoided emissions to demonstrate the enabling potential of the chemical industry to de-carbonize the economy. This study builds upon the methodological guidance provided in the "*Addressing the avoided emissions challenge*" guidelines.[14] The use of such sector-wide guidelines increases the consistency of calculations and the credibility of communicated emission reductions. Six principles are key in calculating of and reporting on avoided emissions: relevance, completeness, consistency, transparency, accuracy and feasibility.

This study highlights chemical solutions that can enable emission reduction compared to conventional solutions currently being used. The calculation of the emission reduction throughout the value chain comes with various methodological issues, including the scope definition, the level in the value chain, the choice of the baseline, consideration of future changes, and the attribution of avoided emissions to different actors in the value chain.

Since avoided emissions can occur throughout the whole value chain, all **life cycle stages** should be addressed (Figure 3). Unfortunately, the need to address all life cycle stages drastically increases the effort required to complete an avoided emissions calculation. To enhance the feasibility of the analysis, a simplified calculation can be performed, in which all life cycle stages that are equal between different products, are omitted from the analysis.[17] The simplified calculation is applied in this report as well.

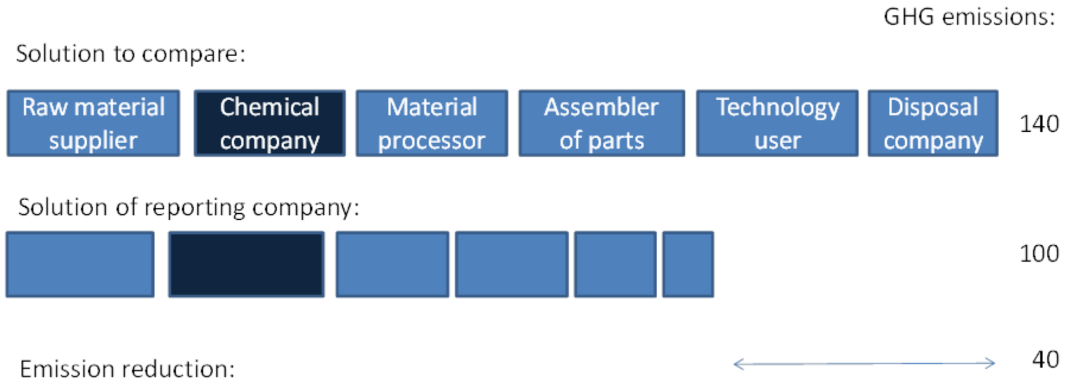

Figure 3. Life cycle avoided emissions by solution of reporting company compared to the solution to compare. Source: ICCA/WBCSD, 2013. *Addressing the Avoided Emissions Challenge.*

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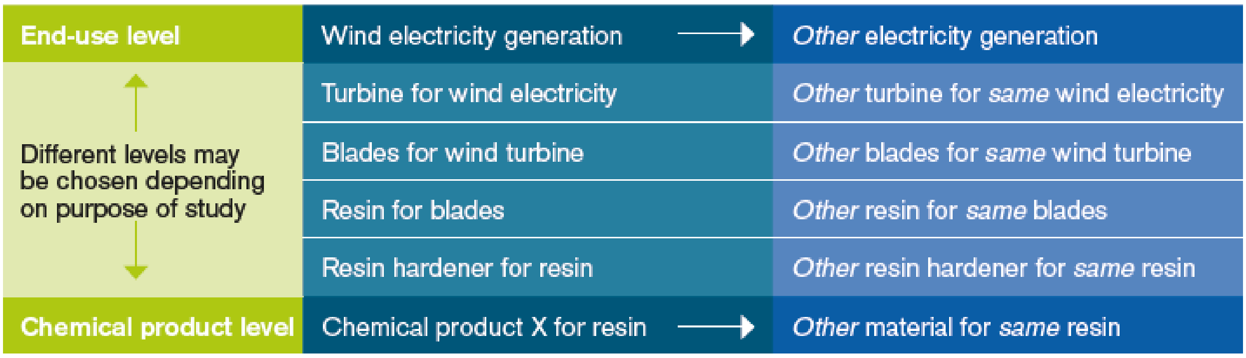
[17] It should be noted that communication on avoided emissions cannot be done using relative figures if certain life cycle stages are excluded.

While avoided emissions occur throughout the whole value chain, comparison can be made at various **levels in the value chain**, i.e., at the product level or at the end use level (Figure 4). When comparing at the product level, the definition of the functional unit takes into account the performance of the chemical product and the alternative product. An example is "Insulating 1 m^2 of an exterior wall using Expanded Polystyrene (EPS) versus stone wool achieving a U-value (wall) of 0.2 $W/(m^2{\cdot}K)$." A comparison at the end use level takes into account the function of the chemical product in the value chain. An example is "Living in an existing single-family detached house in Germany with an average temperature for 40 years (from 2011 to 2051), with polystyrene insulation and without." [18]



End-use level	Wind electricity generation →	*Other* electricity generation
↑ Different levels may be chosen depending on purpose of study ↓	Turbine for wind electricity	*Other* turbine for *same* wind electricity
	Blades for wind turbine	*Other* blades for *same* wind turbine
	Resin for blades	*Other* resin for *same* blades
	Resin hardener for resin	*Other* resin hardener for *same* resin
Chemical product level	Chemical product X for resin →	*Other* material for *same* resin

Figure 4. Different levels in the value chain of wind electricity generation and relevant established alternatives that satisfy the same customer purpose at the respective level. Source: ICCA/WBCSD, 2013. *Addressing the Avoided Emissions Challenge.*

The avoided emissions of a solution with chemical products of fundamental or extensive significance are compared to a certain **baseline**. Usually, this is either a specific alternative or the market average of technologies. The avoided emission guidelines require that in studies conducted at the end-use level the baseline should be the "the weighted average based on shares of all currently implemented technologies for the same user benefit (including the studied end-use solution to which the chemical product contributes)." [19] Also in this study the baseline is defined as the market average of applied technologies.

Avoided emissions can be calculated from different perspectives, i.e. the calculations can be either based on the sales volume of the solution of the reporting company in a specific year (flow-based approach) or on the total amount of the solution implemented in a certain year. If companies would like to compare the avoided emissions related to products sold in a certain year, they base their calculations on the flow of products in a given year, and assess the actual avoided emission over a specific lifetime of the product. Communication is then focused on comparing actual emissions resulting

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[18] Examples are obtained from ICCA/WBCSD, 2013. *Addressing the Avoided Emissions Challenge*.

[19] ICCA/WBCSD, 2013. *Addressing the avoided emissions challenge.* Besides this, the solutions to compare shall be at the same level in the value chain; deliver the same function to the use; be used in the same application; be distributed/used on the market, and not in the process of being banned, in the reference time period and geographic region; be exchangeable for the typical customer in the selected market in terms of quality criteria; be as consistent as possible with the solution of the reporting company in terms of data quality, methodology, assumptions, etc.

from the production of the product with emission reductions that are enabled by that product compared to the life cycle emissions of the baseline alternative. However, policy makers might be interested in the full potential of a certain product to avoid emissions in a certain year, e.g. to get on a 2 degrees Celsius trajectory. For these purposes, the analysis could focus on the potential avoided emissions of products that can be brought to the total market (stock). Figure 5 shows the different perspectives on avoided emissions in a structured manner. In this study we look at the actual and potential avoided emissions from a stock approach.

		Scope	
		Stock	**Flow**
Avoided emissions	**Actual**	Actual avoided emissions in year X by all products implemented in the market at that time	Life time avoided emissions by products sold in year Y.
	Potential	Potential avoided emissions in year X by all products that might be implemented in the market at that time	Potential life time avoided emissions by products that might be sold in the market in year Y.

Figure 5. Avoided emissions using the stock and flow approach. Source: Ecofys.

While the emissions related to the production of the chemical product occur in one specific year, avoided emissions are generally realized over the whole lifetime of the product, which can be up to 50 years, e.g. for insulation materials. The avoided emissions calculations should carefully address potential **future changes**, e.g. reductions in the emission intensity of the space heating mix or reductions in the emission factor of electricity.

Finally, it is important to notice that the avoided emissions occur throughout the whole value chain and cannot be **attributed** to a single actor in that value chain. The chemical industry might, for example, enable emission reductions by producing high performance insulation materials, but it is the user that chooses a certain product and makes the emission reduction happen. The avoided emission guidelines require the total avoided emissions to be allocated to the complete value chain. In addition, one can report on the significance of the contribution of the specific product or industrial sector to the value chain. Also in this report, the total avoided emissions are quantified. The contribution of the chemical industry is qualitatively described.

Table 1 provides a comparison between the *"Innovations for Greenhouse Gas Reductions"* study, the *"Addressing the avoided emission challenge"* guidelines, and this study, on the topics described above.

Table 1. Comparison between the "*Innovations for Greenhouse Gas Reductions*" study, the "*Addressing the avoided emissions challenge"* guidelines, and this study, on key methodological issues.

Topic	Innovations for Greenhouse Gas Reductions (ICCA, 2009)	Addressing the avoided emissions challenge (ICCA/WBCSD, 2013)	This study
Level in the value chain	End-use level	No specific requirements	End-use level
Baseline	Next best non-chemical alternative	Currently implemented mix of technologies in the market	*Potential avoided emissions calculation:* Currently implemented mix of technologies in the market *Scenario analysis:* Implemented mix of technologies in the scenarios
Stock or flow	Realised lifetime avoided emissions by products sold in certain year (flow)	No specific requirements	*Potential avoided emissions calculation:* Avoided annual emissions based on the (potentially) applied technology (stock) *Scenario analysis:* Avoided annual emissions based on the applied technology compared to the reference scenario (stock)
Future changes	Not addressed	Qualitative analysis, or quantitative analysis using one alternative scenario applying a discount factor	*Potential avoided emissions calculation:* Avoided emissions are only reported for recent year. *Scenario analysis:* Future changes are addressed in the scenario analysis
Attribution	All avoided emissions are allocated to the chemical industry	Avoided emissions should be allocated to value chain, contribution to the value chain can be addressed qualitatively	Avoided emissions are allocated to value chain, but contribution to value chain is evaluated qualitatively

2.2 Methodological approach

The avoided emissions by the six solutions are studied using two distinct approaches, which provide insights in the full current avoided emission potential of the solutions (Approach 1) and insights in the contribution of the solutions in a mitigation scenario until 2030 (Approach 2). The results of Approach 1 are provided in Section 3.1. The detailed methodologies and calculations for each of the solutions are provided in the appendix. Because of data limitations, the potential of packaging materials is covered in a less detailed manner compared to the other case studies. The packaging solution is therefore not included in the summary and in the results section. A separate section on packaging in provided in the appendix.

The results of Approach 2 are provided in Section 3.2, which contains four factsheets:

1. Wind and solar power
2. Efficient building envelopes
3. Efficient lighting
4. Fuel efficient tires, lightweight materials and electric cars.

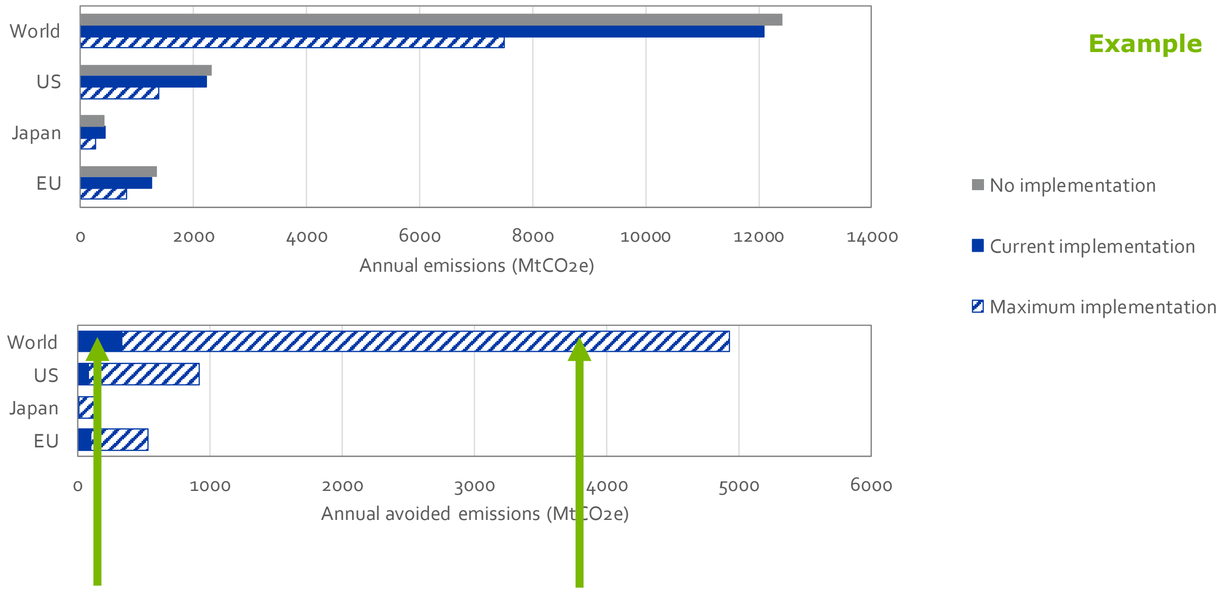
The factsheets highlight the background of the solutions and the contribution of the solutions in the mitigation scenario. More detailed methodologies and calculations are also provided in the appendix.

2.2.1 Current avoided emissions potential (Approach 1)

To showcase the avoided emissions potential of the solutions to which chemical products contributes, we quantify the emissions that would be avoided if each selected solution was used to its full potential right now. We analyse the maximum theoretical use of the solution and quantify how much lower the emissions would be if this was the case, keeping everything else the same. In addition, we quantify the contribution the solution currently makes through its current market share. We calculate the contribution the solution currently makes by calculating how much higher the emissions would be if the solution was not be used at all. The potential avoided emissions calculation assumes that it would be possible to realise an immediate 100% implementation of the alternative solution, and is intended to illustrate the possibilities. The authors realize that this potential is hypothetical and not achievable in a short timeframe and under the given boundary conditions (e.g. limited availability of raw materials, production capacity and infrastructure).

The potential avoided emissions (the first approach as outlined in Section 2.1) are calculated using a bottom-up approach. The avoided emissions potential and realized avoided emissions are analysed by comparing the emissions of the complete life cycle for a situation without the implementation of the solution using chemical products at all ("No implementation"), a situation that represents the current market average of the solution ("Current implementation") and a situation in which the solution using chemical products is applied to its maximum potential ("Maximum implementation"). The difference between the situation without the solution using chemical products and the situation that represents the market average are the realized avoided emissions by the chemical product. The difference between the market average and the full potential are the avoided emissions potential. The avoided emissions are described as net avoided emissions, consisting of increased emissions resulting from the production of the solution and avoided emissions in the use phase. The avoided emissions in the use phase typically exceed the production emissions significantly. In analysing the life cycles in the three situations, a simplified calculation methodology is applied, which means that similar life cycle stages are omitted from the analysis.

The global potential for avoided emissions of each of the solutions is summarized in Section 3.1. A detailed description of the methodology and the results of the avoided emissions potential calculation are provided in the appendix. The detailed results are presented in the appendix with two graphs (Figure 6). The first graph describes the total annual emissions in the "No implementation", "Current implementation” and “Maximum implementation” situations. The second graph describes the annual realized and potential avoided emissions.



Example

Realized avoided emissions

Avoided emissions potential

Figure 6. The upper graph shows the annual emissions related to the chemical product in the “No implementation”, “Current implementation” and “Maximum implementation” situation. The latter graphs shows the annual realized avoided emissions and potential avoided emissions.

2.2.2 Contribution until 2030 in a mitigation scenario (Approach 2)

We also zoom in on emission scenarios until 2030 by comparing the emissions in a mitigation scenario with the emissions in a reference scenario; and calculate the contribution of the selected solutions to the emission reductions in the mitigation scenario compared to the reference scenario. The scenarios are based on the IEA Energy Technology Perspectives (ETP) 2015 scenarios. The ETP scenarios provide detailed insights in sectoral developments with a focus on the technologies applied. The reference scenario is based on the ETP scenario “6DS” that projects a temperature rise of almost 5.5 degrees Celsius (°C) in the long term (by 2050) and almost 4 degrees Celsius by the end of this century. The mitigation scenario is based on the ETP scenario “2DS”, limiting temperature increase to 2 degrees Celsius. Assumptions not specified in IEA ETP 2015 are determined by expert judgement.

The comparison between the reference and the mitigation scenarios follows a top-down approach (the second approach as outlined in Section 2.2) and focusses on the use phase emissions only. This means that emission in the production phase is ignored. This, because while calculating the potential avoided emissions, it was found that the annual increased production emissions related to the production of insulation materials, solar PV panels, wind turbines, and fuel efficient tires were less than 10% of the savings during use. For some transport cases, such as electric cars and lightweight materials, increased production emissions can be more substantial as result of the high emissions related to the production of batteries and lightweight materials, such as carbon fibre reinforced plastics, increasing the uncertainty of the avoided emissions calculation.

The methodology and the results of the scenario analysis are described in detail in the appendix. The results are presented in one graph. The graph describes the total annual emissions in the reference scenario in 2015, the total annual emissions in the reference scenario in 2030 and the total annual emissions in the mitigation scenario in 2030 (Figure 7). The difference between the reference scenario and the mitigation scenario (blue bars) is calculated by replacing all the relevant parameter values that were used in the calculation of the avoided emissions potential with the values defined in the scenario quantification.[20] The difference between the reference scenario and mitigation scenario in 2030 is further analysed to showcase the contribution of the chemical product, amongst the contribution of other factors impacting the annual emission developments. The breakdown of the various factors (green bars and grey bars) is calculated using a decomposition analysis. In the decomposition analysis only one parameter is changed to investigate the impact of that single parameter. The results of the individual steps in the decomposition analysis are subsequently normalized in proportion to their relative non-normalized contribution to yield the overall emission reduction.

The results from the different approaches are difficult to compare, because some of the chemical solutions will already be used in the reference scenario in 2030 as well. The share of wind energy in the electricity mix, for example, is 6% in the reference scenario and 12% in the mitigation scenario, while the current share is 3-4%.

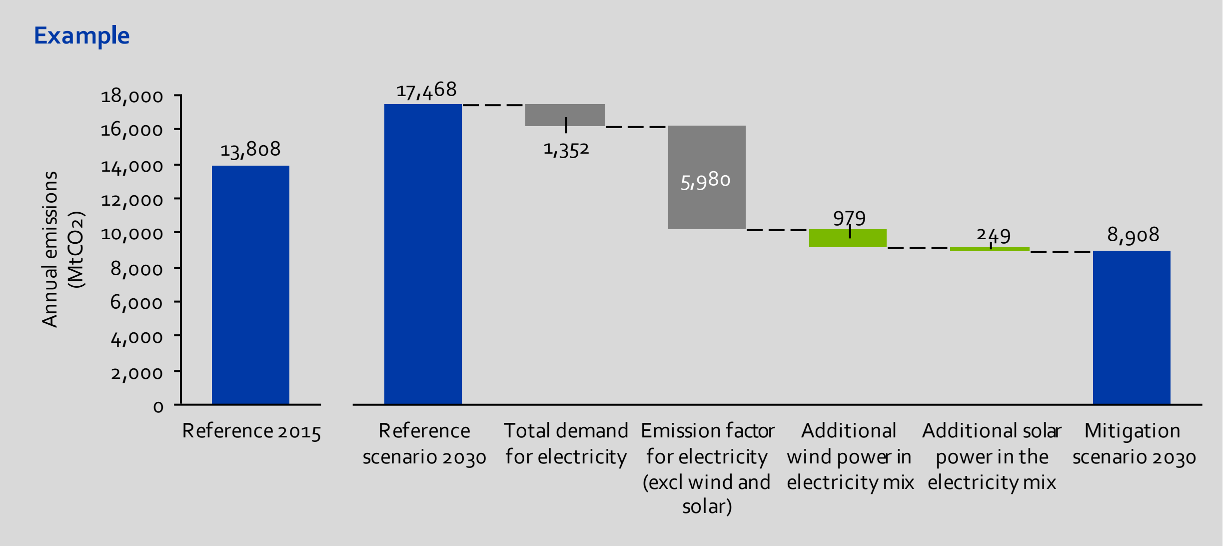


Figure 7. Annual avoided emissions in the mitigation scenario in 2030.

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[20] This is the general approach that was followed. In specific cases other approaches have been used because of data limitations. We refer to the Annex for more detailed information on the parameters and approaches used.

2.2.3 Limitations of the approach

Across the case studies there can be uncertainties about specific assumptions, including the current market share (e.g. the current share of green tires), regional information (e.g. the average U values), efficiency improvement factors (e.g. lightweight materials for the automotive industry), both related to the state of art, as well to potential future developments (e.g. future efficiency improvement of LED light bulbs).

In view of the typical uncertainties related to the type of calculations it should be stressed that the avoided emission potentials presented in his study are to be viewed as approximate values. As an example, a sensitivity analysis in building envelopes shows that a potential for avoided emissions ranges between 0.5 $GtCO_2e$ and 1.3 $GtCO_2e$, while maximum avoided emissions is estimated to be 1.2 $GtCO_2e$.

3 Results

The **avoided emissions potential** of the six quantified solutions together is presented in Section 3.1 and showcase the emissions that would have been avoided if the selected solution would have been used to its full potential right now. The **emission scenarios** are described case by case in the factsheets included in Section 3.2.

3.1 Current avoided emissions potential (Approach 1)

We estimate that global annual emissions would have been over 9 $GtCO_2e$ lower if the selected solutions would be used to their full potential right now (Figure 8), which is substantially more than the current annual emissions of the United States.[21] Renewable energy (such as solar and wind power) as well as energy efficiency measures (such as electric cars, efficient building envelopes and efficient lighting) are major contributors to this potential. This calculation assumes that it would be possible to realise a 100% implementation of the alternative solution overnight, and is intended to illustrate the possibilities; the authors realise that this potential cannot be reached overnight in reality.

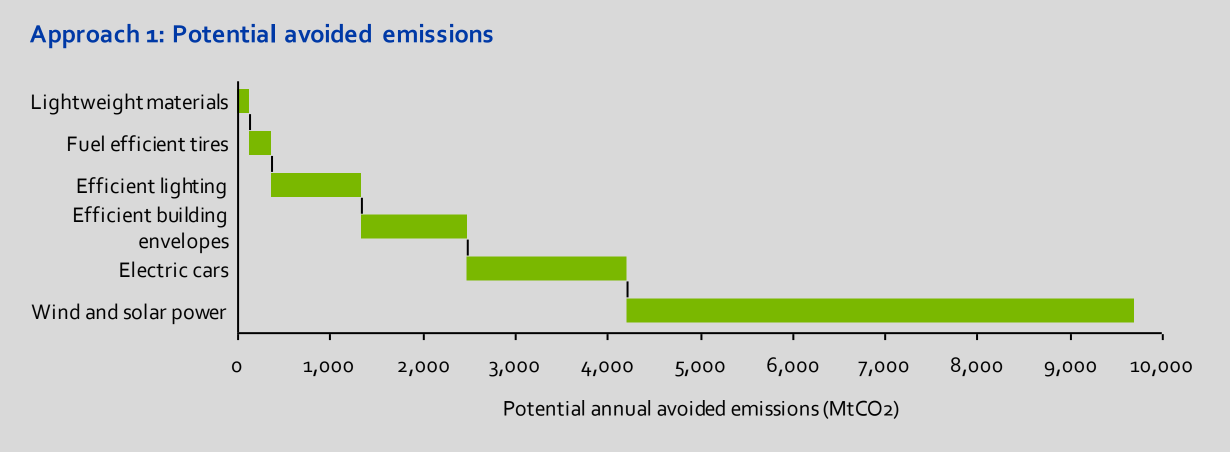

Figure 8. Estimated annual emission reductions if the solutions would be used to their full potential right now. Source: Ecofys analysis.

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[21] The emissions in the United States were 6.3 $GtCO_2e$ in 2012 according to http://edgar.jrc.ec.europa.eu/.

3.2 Contribution in 2030 in a mitigation scenario (Approach 2)

The report also zooms in on actual emission scenarios towards 2030 by quantifying the contribution of the selected solutions in 2030 in a mitigation scenario (limiting temperature increase to 2 degrees Celsius) as compared to a reference scenario.[22] The results of this analysis are provided in the product sections below. The product sections give an introduction to the product group studied, including the contribution of the chemical industry to the production. Furthermore, the emission reductions in the mitigation scenario are compared to those in the reference scenario.

The following product sections will be presented:

1. Wind and solar power
2. Efficient building envelopes
3. Efficient lighting
4. Fuel efficient tires, lightweight materials and electric cars

Figure 9 shows that the selected solutions reduce emissions by 2.5 GtCO$_2$e in 2030 in a 2 degrees Celsius mitigation scenario as compared to a reference scenario. This is equivalent to the annual emissions of France, Germany, Italy and the United Kingdom together.[3] The relative contribution of each of the solutions is comparable to the results obtained using the first approach.

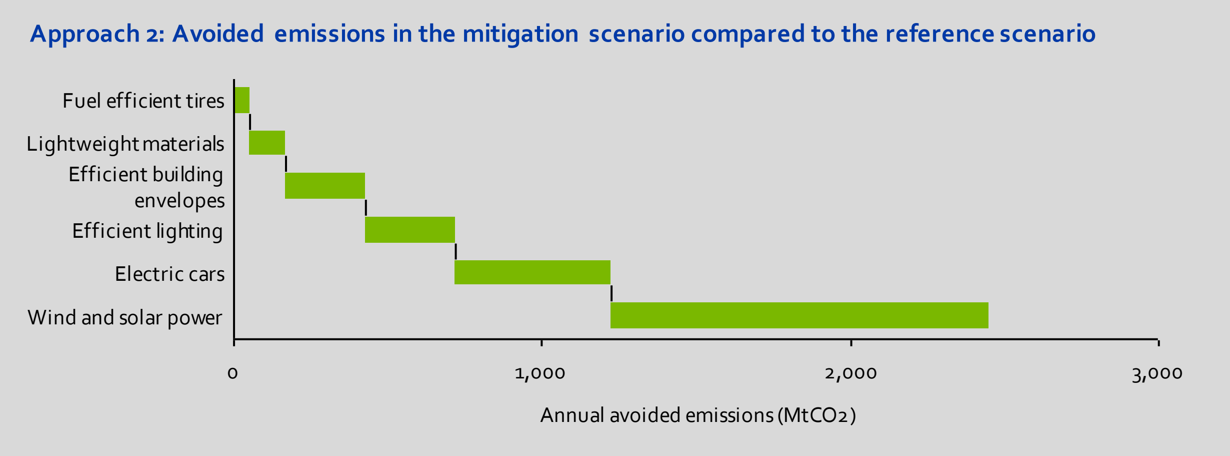

Figure 9. Contribution of the solutions to the GHG emission reductions in 2030 in a 2 degrees Celsius mitigation scenario as compared to a reference scenario. Source: Ecofys analysis.

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[22] The scenarios are based on the IEA Energy Technology Perspectives (ETP) 2015. The reference scenario is based on the 6DS scenario and the mitigation scenario is based on the 2DS scenario from the ETP.

Wind and solar power

Renewable and low carbon electricity, such as wind and solar power, play a key role in the decarbonisation of our energy system. The chemical industry contributes to the deployment of renewables through the supply of key materials for wind turbines and solar PV panels, including gear oils for wind turbine gearboxes, resins for blades and coating materials for wind turbines, and silicon ingots, semiconductor gas and sealant for PV panels. A higher share of renewable energy as result of additional wind and solar power in the electricity mix contributes to over 1200 MtCO_2e of emission reductions in the mitigation scenario as compared to the reference scenario.

Renewable electricity is key in the decarbonisation of the energy system. In all scenarios from the Energy Technology perspectives, installed capacities for electricity production from biomass, hydro, geothermal, wind, solar and ocean will increase. In the 6DS scenario the installed renewable capacity increases to over 3000 GW in 2030. In the 2DS scenario the capacity increases to over 4500 GW in 2030.[23] The share of wind and solar in the electricity mix increases from about 3.5% and 1.0% in 2015 to 5-12% and 2-4% in the various scenarios in 2030.[24] The chemical industry contributes to the deployment of wind and solar power through the supply of key materials for wind turbines and solar PV panels, such as gear oils for wind turbine gearboxes, resins for wind turbine blades, and silicon ingots for PV panels. Emissions related to the production of wind turbines and solar PV panels are small (< 5%) compared to the emission reduction achieved.

Figure 10 shows the development of emissions for electricity in the reference scenario and the mitigation scenario. Additional emission reductions compared to the reference scenario are enabled by electricity demand reductions and, most importantly, decarbonisation of the electricity mix. Besides wind and solar power, decarbonisation is achieved by the deployment of bioenergy, geothermal energy, hydro energy as well as nuclear energy and by the use of lower carbon fossil fuels (e.g. a shift from coal to gas). A higher share of renewable energy as result of additional wind and solar power in the electricity mix contributes to over 1200 MtCO_2e of emission reductions in the mitigation scenario.

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[23] IEA, 2015. Energy Technology Perspectives. Gross electricity capacity for biomass and waste, biomass with CCS, hydro (excl. pumped storage), geothermal, wind onshore, wind offshore, solar PV, solar CSP, and ocean.

[24] IEA, 2015. Energy Technology Perspectives. Calculated by (Gross electricity generation from offshore wind + Gross electricity generation of electricity from onshore wind) / Total gross electricity generation of electricity and Gross electricity generation of electricity from solar PV) / Total gross electricity generation of electricity

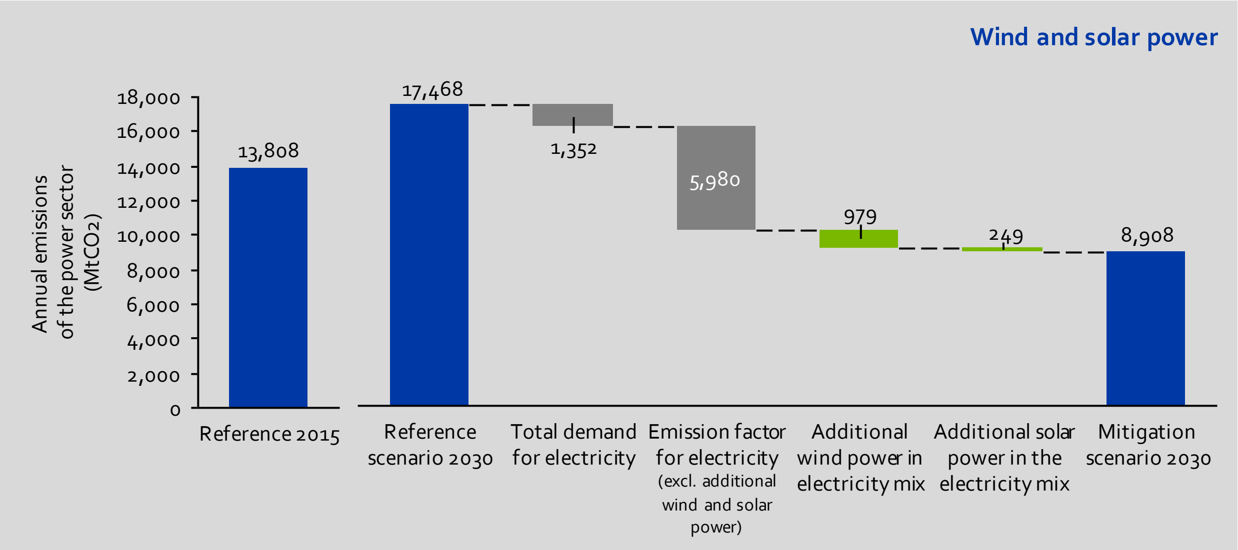

Figure 10. Annual avoided emissions from additional wind and solar power in the mitigation scenario in 2030. Source: Ecofys analysis based on ETP scenarios.

More details on the avoided emissions potential and the scenario analysis can be found in Section 5.2.

Efficient building envelopes

Emissions related to space heating of buildings represent a significant share of global GHG emissions. Deep renovation could result in energy efficiency improvements up to 80% in existing buildings. The chemical industry contributes to deep renovation through the production of wall and roof insulation materials like expanded polystyrene (EPS) and polyurethane (PUR), or key components of windows and doors. The annual emission reduction from additional residential efficient building envelopes including additional insulation in the mitigation scenario will amount to over 250 $MtCO_2e$ in 2030 as compared to the reference scenario.

Emissions related to both residential and commercial buildings represent a significant share of global GHG emissions. Over 6% of global GHG emissions are directly emitted by the building sector and buildings are also responsible for a further 12% of global emissions resulting from indirect emissions.[25] The IEA recommends member countries to focus on both deep energy renovations of the existing building stock and on strict building codes for new building, with the eventual goal of near zero or zero energy buildings.[26]

Studies on reducing energy consumption and emissions from heating and cooling (which are responsible for 36% of global building energy consumption[27]) are numerous including the IEA study on the "*Transition to Sustainable Buildings*", work by the Global Building Performance Network (GBPN), and regional work such as the studies done by Ecofys for the European insulation industry.[26,26,28] Although the studies obviously differ in scope and set-up, conclusions are often similar pointing at the low or even negative costs of many of the mitigation options available and the many co-benefits and the existence of strong barriers (e.g. related to upfront investment needs). The need for high performance retrofit as mitigation strategy is also highlighted.[25]

Avoided emissions from building envelope improvement and energy efficiency in the residential building sector are dominated by the reduction in heating fuel consumption during the use phase. Deep renovation could result in energy efficiency improvements up to 80% in existing buildings. The

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[25] IPCC, 2014. Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Chapter 9: Buildings. According to IPCC (2014) the GHG emissions from the buildings sector reached over 9 GtCO2e in 2010, representing 19% of all global GHG emissions. One third is related to direct emissions and two third is related to indirect emissions. Indirect emissions are emissions related to electricity use and (district) heat consumption.

[26] IEA, 2013. Transition to Sustainable Buildings. Strategies and Opportunities to 2050.

[27] According to IPCC, 2014, the final energy consumption for space heating and cooling amount to 32% and 4% in the residential sector and 33% and 7% in the commercial sector. Other large categories are water heating (24%) and cooling (29%) in the residential buildings. and lighting (16%) and other (including IT equipment) (32%) in the commercial buildings. In cold climates the share of space heating can be substantially higher.

[28] Ecofys, 2012. Renovation Tracks for Europe up to 2050. Available at: http://www.ecofys.com/en/publication/renovation-tracks-for-europe-up-to-2050.

chemical industry contributes to deep renovation through the production of insulation materials like EPS and PUR. The chemical industry, together with competing insulation materials such as rock and glass wool), is of essential importance in tapping the CO_2 emissions related to the existing building stock, which can result in CO_2 savings of up to 80-90%.[28] Emissions related to the production of the insulation material are marginal compared to the use phase emissions.

Figure 11 shows the development of emissions for residential space heating in the reference scenario and the mitigation scenario. Additional emission reductions compared to the reference scenario are enabled by building envelope improvements,[29] as well as a reduction in the carbon intensity for space heating. The annual emission reduction from additional efficient building envelopes including additional insulation in the mitigation scenario will amount to over 250 $MtCO_2e$ in 2030. In addition, improving the energy efficiency of buildings has a lot of co-benefits beyond climate change mitigation, such as increased comfort levels.

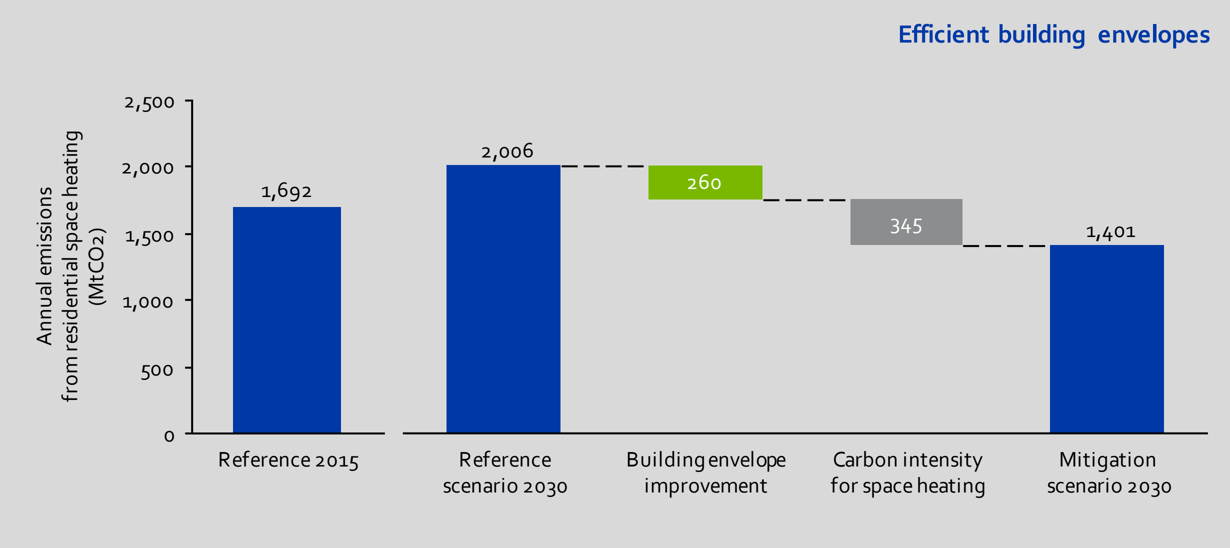

Figure 11. Annual avoided emissions from additional residential efficient building envelopes in the mitigation scenario in 2030. Source: Ecofys analysis based on ETP scenarios.

More details on the avoided emissions potential and the scenario analysis can be found in Section 5.3.

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[29] Building envelope improvements include, amongst other, improve floor, wall and roof insulation, efficient windows and efficient technologies used for energy conversion.

Efficient lighting

Substantial opportunities exist to improve the energy efficiency of appliances in buildings. LED (light-emitting diode) light bulbs are new and highly energy efficient light bulbs, that have a much higher luminous efficiency than conventional light bulbs such as incandescent bulbs and halogen bulbs. The energy efficiency potential of LED light bulbs is up to 80% compared to what is currently applied in the market. Chemical products, such as semiconductor gas, phosphor, substrate, and sealant, are essential materials to enable high energy efficiency, reliability, and long life of LED light bulbs. Energy efficiency improvement as a result of additional efficient lighting will contribute to an annual emission reduction of approximately 300 MtCO$_2$e in 2030 as compared to the reference scenario.

Global emissions related to lighting in buildings were over 1000 MtCO$_2$e in 2015. While LED light bulbs have much higher luminous efficiency that other light bulbs, their current market penetration is rather limited. Increasing market penetration and further energy efficiency improvement will result in substantial emission reductions. The energy efficiency potential of LED light bulbs is up to 80% compared to what is currently applied in the market.[30] Chemical products, such as semiconductor gas, phosphor, substrate, and sealant, are essential materials to enable high energy efficiency, reliability, and long life of LED light bulbs. Without these newly developed materials for LED, performance of LED would have been much lower than the current level.

Figure 12 shows the development of emissions for lighting in the reference scenario and the mitigation scenario. Emission reductions are enabled by deployment of energy efficient lighting, such as LED lamps, as well as decarbonisation of the electricity mix. Energy efficiency improvement as a result of additional efficient lighting will contribute to an annual emission reduction of approximately 300 MtCO$_2$e in 2030. Deployment of LED light bulbs has a lot of co-benefits beyond climate change mitigation, including a reduction of life cycle costs for lighting compared to conventional light bulbs and an improved safety compared to kerosene lighting in developing countries.

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[30] Calculated based on a current average luminous efficiency of 30 lm/W, compared to a LED luminous efficiency of 150 lm/W, which represent the current state-of-art technology.

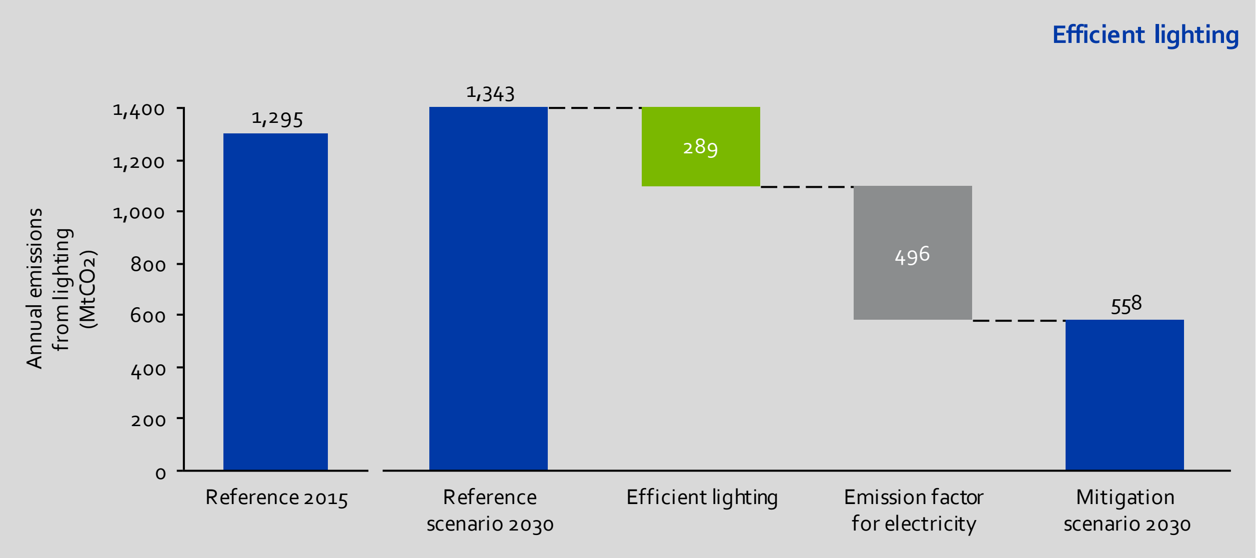

Figure 12. Avoided emissions from additional efficient lighting in the mitigation scenario in 2030. Source: Ecofys analysis based on ETP scenarios.

More details on the avoided emissions potential and the scenario analysis can be found in Section 5.4.

Fuel efficient tires, lightweight materials and electric cars

Multiple options to reduce GHG emissions in the road transport sector need to be tapped to address climate change. Emission reductions can be enabled by transport demand reductions, but also by efficient technologies, such as fuel efficient tires, lightweight materials and electric cars. The emission reduction potential of fuel efficient tires in the mitigation scenario amounts to over 50 $MtCO_2e$ in 2030, the emission reduction potential of lightweight materials amounts to over 100 $MtCO_2e$ and the emission reduction potential of electric cars amounts to over 500 $MtCO_2e$, all as compared to the reference scenario.

Road transport (including cars, busses, and trucks) accounts for more than two third of the final energy consumption for transport.[31] Roughly 20% of automobiles' fuel consumption is used to overcome rolling resistance of the tires.[32] Fuel efficient tires have lower rolling resistance compared to normal tires, while providing enhanced road-gripping performance, resulting in an energy efficiency improvement of about 2.5%.[33] Chemical products such as synthetic rubbers and silica are key components in reducing energy loss and enabling improved fuel efficiency of tires. Application of additional fuel efficient tires will contribute to an annual emission reduction of over 50 $MtCO_2e$ in 2030.

Electrification of road transport enables deep decarbonisation of the energy demand when renewable electricity is supplied on a large scale. Furthermore, electric cars have a higher energy efficiency compared to cars with conventional combustion engines. Chemical products play a key role in the production of batteries required for electric cars. These include anode materials, cathode materials, electrolyte and separators. More electric cars in the mitigation scenario will contribute to an annual emission reduction of more than 500 $MtCO_2e$ in 2030.

Lightweight materials reduce the fuel demand of cars. Innovative lightweight materials have the potential to reduce car weight substantially. However, historically, car weight is rather constant as a result of higher safety requirements, bigger cars, and more appliances. Chemical products such as plastics and carbon fiber reinforced plastics are key in achieving strong weight reductions of cars. Additional lightweight materials in the mitigation scenario will contribute to an annual emission reduction of more than 100 $MtCO_2e$ in 2030.

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[31] Final energy consumption for road transport for passengers and freight account for 80 EJ compared a total final energy consumption for transport of 103 EJ in 2012 according to IEA, 2015. Energy Technology Perspectives.

[32] IEA, 2005. Energy Efficient Tyres: Improving the On-Road Performance of Motor Vehicles, IEA Workshop, 15-16 November 2005, OECD/IEA, Paris, www.iea.org/work/2005/EnerEffTyre/summary.pdf.

[33] ICCA/JCIA, 2015. Case Study: Materials for Fuel Efficient Tires. Available at: http://www.icca-chem.org/Public/Avoided%20Emissions%20Case%20Studies/Case%20study%201%20-%20Avoided%20Emissions%20Guideline%20-%20JCIA.pdf

Figure 13 shows the development of emissions for transport in the reference scenario and the mitigation scenario. Emission reductions are enabled by demand reductions, fuel efficient tires, lightweight materials, electrification as well as many other efficiency improvement measures. In the mitigation scenario, additional fuel efficient tires contribute to over 50 $MtCO_2e$, additional lightweight materials contribute to over 100 $MtCO_2e$ and additional electric cars contribute to over 500 $MtCO_2e$.

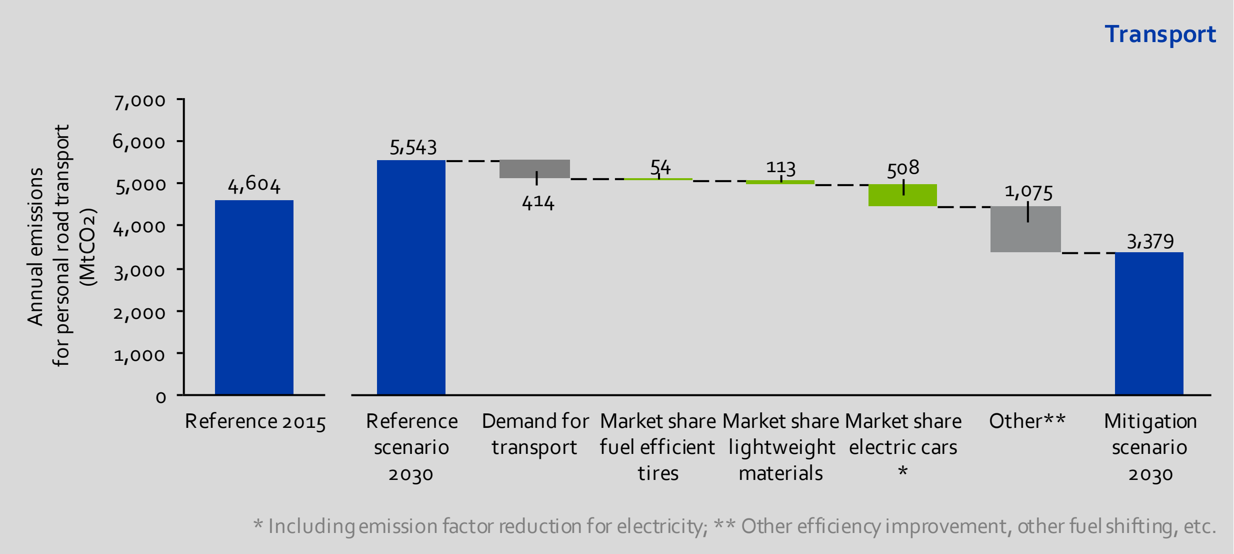

Figure 13. Annual avoided emissions from fuel efficient tires, lightweight materials, and electric cars in the mitigation scenario in 2030. Source: Ecofys analysis based on ETP scenarios.

More details on the avoided emissions potential and the scenario analysis can be found in Section 5.5-5.8.

4 Conclusion

It is estimated that annual global emissions would be over 9 $GtCO_2e$ lower if the selected solutions with chemical products of fundamental or extensive significance were used to their full potential right now. This exceeds the current annual emissions of the United States.[21] Renewable energy (such as solar and wind power) as well as energy efficiency measures (such as efficient building envelopes, electric cars and efficient lighting) are major contributors to this potential. In addition, the contribution the solutions currently already make through their current market shares was quantified.

The report also zooms in on actual emission scenarios towards 2030 by quantifying the contribution of the selected solutions in 2030 in a mitigation scenario (limiting temperature increase to 2 degrees Celsius) as compared to a reference scenario. The study shows that the selected solutions contribute up to 2.5 $GtCO_2e$ to the difference between these two scenarios in the year 2030.[34] This is equal to 14% of the total mitigation effort required in 2030 to move from the reference scenario towards the mitigation scenario and equivalent to the current annual emissions of France, Germany, Italy and the United Kingdom together.[35] In view of the typical uncertainties related to the type of calculations it should be stressed that the avoided emission potentials presented in his study are to be viewed as indicative only.

Many industrial and other stakeholders work together for each of the studied solutions. Enhanced value chain cooperation is needed to fully exploit the potential. The chemical industry is, for example, committed to providing energy efficient solutions to the buildings sector, by efforts such as participation in pilot projects, sponsoring life cycle assessment studies, investments in research and development, and cooperation with the value chain; from architects to craftsmen.[36]

An enabling policy environment is needed, stimulating greenhouse gas emission reductions along the full value chain, including use and end-of life phases.

- Governments should establish technology neutral policies which enable cost effective **renewable energy** to grow and contribute to greenhouse gas emission reductions, while ensuring the reliable, affordable, and non-intermittent supply of electricity. Financial support should only be available for research and technology development of pre-commercial innovative technologies. All technologies should be integrated into normal market conditions, removing subsidies as soon as the technology is commercial**.**

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[34] It should be noted the use of some of the chemical solutions will increase also in the reference scenario in 2030 as compared to the situation nowadays. Part of the potential identified following the first approach will thus also already be tapped in the reference scenario.

[35] The mitigation effort according to the IEA ETP scenarios (6DS versus 2DS) is 17.2 $GtCO_2e$ according to IEA, 2015. Energy Technology Perspectives, Figure 1.6. The emissions of France, Germany, Italy and the United Kingdom were 2.5 $GtCO_2e$ in 2012 according to http://edgar.jrc.ec.europa.eu/.

[36] *ICCA, 2015. ICCA Building Technology Roadmap: The Chemical Industry's Contributions to Energy and Greenhouse Gas Savings in Residential and Commercial Construction.* Executive summary available at: https://www.icca-chem.org/wp-content/uploads/2015/08/ICCA-Building-Technology-Roadmap-Executive-Summary.pdf.

- **Energy efficient** measures have a large potential of saving energy and reducing greenhouse gas emissions worldwide. Governments should, for example, set energy efficiency standards, encourage manufacturers to provide correct and easy-to-understand information, and take necessary actions to raise public awareness depending on regional/national circumstances.

Further work is needed, also by the modelling teams, to shed more light on the exact impact mitigation will have on the material demand and resulting emissions of the chemical industry itself; a somewhat unexplored issue in the current modelling due to the focus on the use phase of emissions in the scenario work.

The selected solutions highlight the opportunities of the chemical industry in a low carbon world. The chemical industry has the potential to contribute even more and to further accelerate its contribution also beyond the 2030 timeframe. For all solutions to be used widely, joint action from all partners in the value chain is needed, as well as different business models, supported by a sufficiently enabling policy conditions at an adequate level.

5 Appendix

This appendix provides the detailed methodology and calculations for the seven solutions studied. In Section 5.1 the emission factors used in the potential avoided emissions calculation are described. In Section 5.2 to 5.9 the case studies are described. The case study descriptions contain an overview of the contribution of the chemical industry toward this solution, the methodology and calculation details for the potential avoided emissions and the methodology and calculation details for the scenario analysis. Finally, the references used in the case studies are provided.

5.1 Emission factors

In Section 5.1.1 and Section 5.1.2 the direct and life cycle emission factors for fuels, heat and electricity are provided for various regions in the world. These factors are used in the potential avoided emissions calculations for the case studies. Direct emissions are those emissions related to solely the combustion of fuels at the generation facility. Life cycle emissions include emissions related to all other activities in the life cycle, e.g. raw material extraction, power plant construction, power plant maintenance and waste disposal. Note that the direct emission factors of electricity and heat differ per region due to a different heat (Ecofys/IEE Japan, 2015) and electricity mix (IEA, 2014). The emission factors of electricity are highly dependent on the fuel mix. As result of generation inefficiencies and a limited share of renewables in the energy mix, the emission factors of electricity generation are generally higher per kWh of electricity compared to those for the combustion of fossil fuels per kWh of fuel. The indirect emissions (life cycle emissions excluding direct emissions) are assumed to be the same for different regions. The life cycle emission factors are calculated by multiplying the direct emission factors with an indirect emission correction factor.[37]

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[37] The indirect emission correction factors are calculated based on the energy requirements for energy, which describe the primary energy that is required to extract and deliver one unit of energy. The following values are used for coal: 1.07, gas/diesel/fuel oil: 1.12, kerosene: 1.12, natural gas: 1.03, LPG/natural gas liquids: 1.03, heat: 1, geothermal: 1, combustion renewable and waste: 1, electricity: 1.19. The indirect emission correction factor for coal, oil products and natural gas are based on ranges provided in Blok (2007). The indirect emission correction factor for electricity is calculated on a rough estimate of the shares of coal (40%), oil (4%) and natural gas (22%) in the global electricity mix, in combination with information on the direct and indirect emissions in following Ecoinvent processes: Hard coal, burned in power plant/NORDEL U (direct: 0.094, total: 0.113, ratio: 1,20), Heavy fuel oil, burned in power plant/RER U (direct: 0.079, total: 0.080, ratio: 1.015) and Natural gas, burned in power plant/UCTE U (direct: 0.045, total: 0.068, ratio: 1.218). The life cycle emission factor for electricity is generally higher compared to the life cycle emission factor for burning fossil fuels, because electricity production requires, beside infrastructure for fossil fuel extraction, also infrastructure for electricity generation. For heat, geothermal and combustion renewable and waste the correction factor is assumed to be 1.

5.1.1 Direct emission factors

Table 2. Direct emission factors ($MtCO_2e/TWh$). Source: IEA, 2014; Ecofys/IEE Japan, 2015

Energy carrier	Region								
	World average (default)	Non-OECD (average)	EU	Japan	US	Brazil	Middle East	Russian Federation	China
Coal	0.341								
Gas/diesel/fuel oil	0.267								
Kerosene	0.259								
Natural gas	0.202								
LPG/NGL	0.227								
Heat	0.382	-	0.361	0.495	0.495	0.068	0.068	0.332	0.711
Geothermal	0.000								
Combustion renewable and waste	0.000								
Electricity	0.533	0.629	0.346	0.418	0.522	0.086	0.595	0.437	0.764

5.1.2 Indirect emission factors

Table 3. Life cycle emission factors (including direct and indirect emissions) ($MtCO_2e/TWh$).

Energy carrier	Region								
	World average (default)	Non-OECD (average)	EU	Japan	US	Brazil	Middle East	Russian Federation	China
Coal	0.365								
Gas/diesel/fuel oil	0.299								
Kerosene	0.290								
Natural gas	0.208								
LPG/NGL	0.234								
Heat	0.382	-	0.361	0.495	0.495	0.068	0.068	0.332	0.711
Geothermal	0.000								
Combustion renewable and waste	0.000								
Electricity	0.634	0.749	0.412	0.497	0.621	0.102	0.708	0.520	0.909

* Note that the life cycle emission factor for gas/diesel/fuel oil has been used as a default emission factor in the calculation of transport activities. Based on an energy content of 36.4 MJ/L fuel, the emission factor is equal to 3.032 gCO_2e/L fuel.

5.1.3 References

Blok, 2007. Introduction to Energy Analysis.

IEA, 2014. CO_2 Emissions from Fuel Combustion.

Ecofys/IEE Japan, 2015. Development of sectoral indicators for determining potential decarbonisation opportunity. Available at: http://www.ecofys.com/files/files/ieej-ecofys-2015-development-of-sectoral-indicators.pdf

5.2 Wind and solar power

5.2.1 Contribution of chemical industry

The chemical industry fundamentally or extensively contributes to the deployment of renewables through the supply of key materials for wind turbines and solar PV panels. The chemical industry provides key materials to renewable power generation systems, including gear oils for wind turbine gearboxes, resins for blades and coating materials for wind turbines, and silicon ingots, semiconductor gas and sealant for PV panels. Besides the contribution to wind and solar power, the chemical industry can also play a fundamental role in the large scale energy storage required with higher shares of renewables.

5.2.2 Avoided emissions potential calculation

Functional unit

The selected functional unit is generating worldwide electricity in 2012, which is equal to 22,668,076 GWh (IEA, 2012). The ICCA/WBCSD guidelines state that the solutions to compare shall deliver the same user function. This implies that when wind and solar energy is compared with fossil-based energy, which has a full-time availability, wind and solar energy should be backed with an energy storage system to be comparable. Modelling an entire energy system with storage possibilities is out of scope for this study. As a result, the decision has been made not to account for energy storage, but to focus on a realistic potential share of wind and solar electricity generation instead of a technical potential share. With this simplified approach it is also assumed that the reliability of the electricity system can be guaranteed with the current installed capacity. The potential avoided emissions are calculated by the difference in life cycle GHG emissions from an electricity mix with a realistic percentage of wind and solar and the current electricity mix.

Solutions to compare

Three solutions to compare are analysed, including no implementation, current implementation and maximum implementation of electricity generation by wind and solar (Table 4). All other energy sources, like gas, coal, nuclear and hydro are grouped in and referred to as “other energy sources”. In contrary to other case studies the “maximum implementation” of wind and solar power is considered to be lower than 100%. This is because electricity generation by solely wind and solar cannot provide the same system function compared to the current generation mix (security of supply). A fully renewable electricity mix requires, besides wind and solar generation capacity, also back-up capacity that is not dependent on weather patterns, such as hydropower plants, biofuel plants and storage facilities. Whereas in other case studies the solution "maximum implementation" is focused on a technical potential, in this case study the decision has been made to derive the share of wind and solar from the 450 scenario of the World Energy Outlook for 2040 (OECD/IEA, 2015). The percentage of renewables in the 450 scenario is based on a 50% probability of limiting the average global temperature increase to the international goal of below 2 degrees Celsius.

Table 4. Solutions to compare.

Solutions	Explanation
No implementation of wind and solar	This represents a hypothetical 2012 situation without wind and solar electricity generation.
Current implementation of wind and solar	This is the present electricity mix in 2012.
Maximum implementation of wind and solar	This represents a hypothetical situation with a maximum share of wind and solar electricity generation in the electricity mix. Assumption based on the World Energy Outlook (OECD/IEA, 2015).

Calculation sequence and key data sources

The avoided emissions are calculated by the difference in the life cycle GHG emissions associated with generating electricity in 2012 (baseline). Total GHG emissions per solution to compare are calculated as follows:

- Production and end-of-life phase:
  - Calculation of GHG emissions by multiplying the amount of electricity generated by solar, wind and other energy sources with the production and end-of-life emission factor of wind, solar and other energy sources per TWh.
- Use phase:
  - Calculation of emission factor of the total electricity mix for the three solutions to compare based on the share of wind, solar and other energy sources:
    - Starting point is the emission factor of the electricity mix in 2012, which is derived from the IEA CO_2 Emissions database (IEA, 2014).
    - Calculation of the direct emission factor of "wind", "solar" and "other energy sources". The direct emission factor of "solar" and "wind" is zero. The direct emission factor of "other energy sources" is calculated based on the emission factor of the current electricity mix and the shares per energy source (i.e. percentage wind, solar and other) (see "calculated parameters" for a detailed explanation).
    - Calculation of the emission factor of the total electricity mix per solution to compare (excl. current implementation, which is already known) based on the share of "solar", "wind" and "other energy sources" and the related emission factors.
  - Calculation GHG emissions by multiplying calculated emission factor per solution to compare by the amount of electricity generated per region.
- The realized and potential avoided emissions are determined by respectively the difference between the solutions to compare "no implementation" and "current implementation", and the difference

between the solutions to compare “current implementation” and “realistic maximum implementation”.

Input data sources and assumptions

Table 5 shows the electricity generation in 2012 for the four regions under study: Europe, Japan, US and whole world (“World total”). Table 6 shows the market shares of wind, solar and other energy sources per solution to compare. Note that the World Energy Outlook does not provide a regional breakdown of the maximum potential wind and solar in line with the 450 scenario. The shares for the solution “current implementation” are derived from the IEA Energy Balance (2012).

Table 5. Total electricity generation in 2012. Source: IEA Energy Statistics, 2012.

	Europe	Japan	United States	World total
Total electricity generation (GWh)	3,602,664	1,026,146	4,270,771	22,668,076

Table 6. Market shares wind, solar and other energy sources per solution to compare.

	Europe	Japan	United States	World total
No implementation				
Market share wind	0%			
Market share solar	0%			
Market share other	100%			
Current implementation				
Market share wind	6%	0%	3%	2%
Market share solar	2%	1%	0%	1%
Market share other	92%	99%	97%	97%
Maximum implementation				
Market share wind	29%			
Market share solar	13%			
Market share other	59%			

Table 7 shows the production and end-of-life emission factor of wind, solar and other energy sources. The emission factors of wind and solar are based upon a NREL harmonization study (2012), which indicates the average full life cycle emission factor of various energy sources (incl. wind and solar). Since wind and solar have a direct emission factor (i.e. emission factor during power generation) of zero, the full life cycle emissions factor could directly be derived from the NREL study. The production and end-of-life emission factor of “other energy sources” is calculated by subtracting the direct emission factor of electricity generation from the life cycle emission factor of electricity generation. The latter one is calculated by multiplying the direct emission factor of electricity generation by the indirect emission factor correction (Table 2 and Table 3).

Table 7. Production and end-of-life emission factors wind, solar and other energy sources. Source: NREL, 2012.

Energy carrier	Emission factor (gCO_2e/kWh)			
	Europe	Japan	United States	World total
Wind	10	10	10	10
Solar	40	40	40	40
Other energy sources	66	79	99	101

The direct emission factor of wind and solar during use is zero. The direct emission factor of other energy sources is calculated in the next section.

Calculated parameters

The direct emission factor of "other energy sources" in the current electricity mix is calculated as follows (EF stands for direct Emission Factor; P stands for Percentage (i.e. market share)): $EF_{other} = EF_{total} / P_{other.}$ Table 8 shows the calculated direct emission factor of "other energy sources" for each region. These values are calculated based on the inputs above.

Table 8. Calculated direct emission factor other energy sources and assumptions for direct emission factor wind and solar.

Energy carrier	Emission factor (gCO_2e/kWh)			
	Europe	Japan	United States	World total
Other energy sources	375	423	541	548
Wind	0	0	0	0
Solar	0	0	0	0

Results

Table 9 shows the sum of the emissions during production, end-of-life and use for the three different solutions to compare. Global emissions related to electricity generation were 14.3 $GtCO_2e$ in 2012. This figure is in line with the reported CO_2 emissions in 2012 by the IEA on "main activity electricity plants", which is equal to 10.2 $GtCO_2e$, and "main activity electricity and heat production", which is equal to 12.1 $GtCO_2e$. These values are somewhat lower because IEA only reports on direct emissions. If the share of wind and solar would increase in line with the 2 degrees Celsius limit the emissions would be 5.5 $GtCO_2e$ lower.

Table 9. Annual (avoided) emissions for electricity from wind and solar.

Solutions to compare	Emissions ($MtCO_2e$)			
	Europe	Japan	United States	World total
No implementation	1,587	515	2,734	14,710
Current implementation	1,471	509	2,639	14,318
Maximum implementation	962	311	1,642	8,834

Solutions to compare	Emissions (MtCO₂e)			
	Europe	Japan	United States	World total
Annual realised avoided emissions – Current implementation level	116	6	95	392
Annual avoided emissions potential – Maximum implementation level	509	198	997	5,484

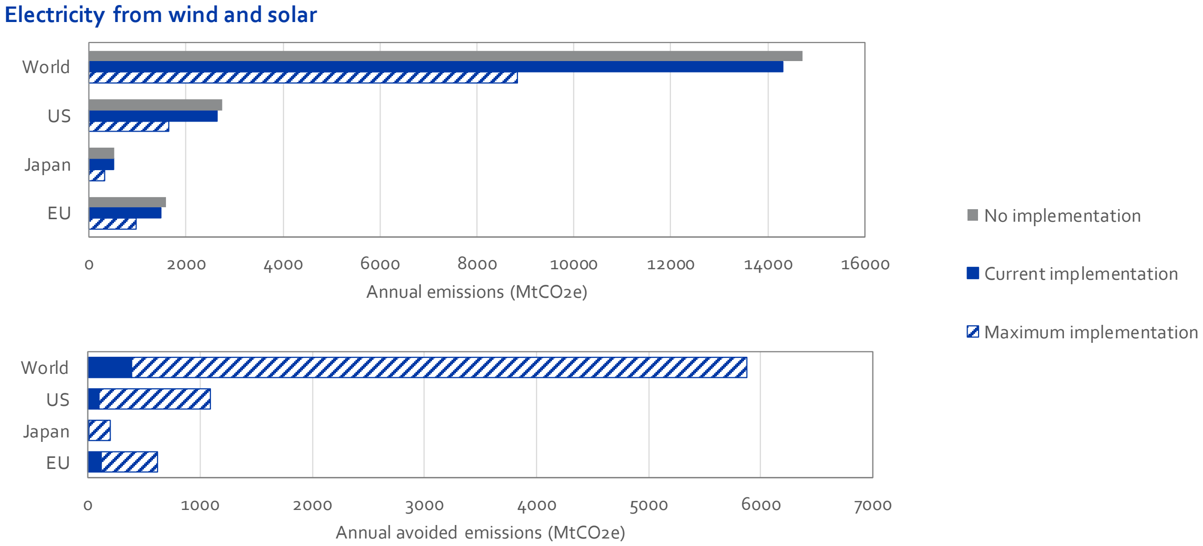

Figure 14. Annual (avoided) emissions for electricity from wind and solar power. First graph shows the annual emissions related to electricity generation, the second graph shows the annual realized and potential avoided emissions.

5.2.3 Scenario analysis

In the scenario analysis the contribution of wind and solar power in reaching the mitigation scenario is investigated. In the following sections we discuss the scenario parameters, differences between the potential avoided emissions calculation and the scenario analysis, as well as the results of the scenario analysis.

Parameters

The scenario analysis uses the calculation methodology of GHG emissions as described in the avoided emissions potential calculation, but certain parameter values are changed to investigate the contribution of wind and solar power in the mitigation scenario compared to the reference scenario. Scenario parameters include the total final demand for electricity, the emission factor of the electricity mix and the share of wind and solar power in the electricity mix. All parameter values are obtained from the ETP 2015 scenarios. In the analysis, the emission factor of the electricity mix is corrected in order to represents the emission factor excluding wind and solar power.

To calculate the difference between the reference scenario and the mitigation scenario (blue bars) all relevant parameter values from the avoided emissions potential calculation are updated according to the scenario quantification (Table 11). The breakdown of the various factors (green bars and grey bars) is calculated using a decomposition analysis. In the decomposition analysis only one parameter is changed to investigate the impact of that single parameter. The results of the individual steps in the decomposition analysis are subsequently normalized in proportion to their relative non-normalized contribution to yield the overall emission reduction. The decomposition formula is provided in Section 5.10.1.

Table 10. Source and calculation methodology for scenario parameters.

Scenario parameter	Source
Total final demand for electricity	Obtained directly from the ETP 2015 electricity tables.
Emission factor for electricity	Calculated using *emissions from power generation / total final demand for electricity*, which are obtained from the ETP 2015 electricity tables. Note that emissions from power plants refer to direct emissions.
Emission factor for electricity excluding wind and solar	Calculated using *emission factor for electricity excluding wind and solar power = emission factor for electricity / (1 – share wind in the electricity mix – share of solar in the electricity mix)*.
Share of wind in the electricity mix	Calculated using *(gross generation of electricity from offshore wind + onshore wind) / gross generation of electricity*, which are obtained from the ETP 2015 electricity tables.
Share of solar in the electricity mix	Calculated using *gross generation of electricity from solar PV / gross generation of electricity*, which are obtained from the ETP 2015 electricity tables.

Table 11. Quantification of scenario parameters for electricity from wind and solar case study.

Parameter	Unit	2015	2030	
		Reference	Reference	Mitigation
Total final demand for electricity	TWh	20,862	29,741	27,108
Emission factor for electricity	$MtCO_2/TWh$	0.662	0.587	0.329
Emission factor for electricity excluding wind and solar	$MtCO_2/TWh$	0.692	0.637	0.387
Share of wind in the electricity mix	%	3.4	5.8	11.7
Share of solar in the electricity mix	%	1.0	2.0	3.5

Discussion of major differences between avoided emissions potential calculation and scenario analysis

- The base year in the avoided emissions potential calculation (2012) is different from the base year in the scenario analysis calculation (2015) resulting in slightly different values for the key parameters.

- The maximum share in the avoided emissions potential calculation is obtained from the WEO scenarios, where the actual share in the scenario analysis calculation is obtained from the ETP scenarios.
- The avoided emissions potential calculation is based on the gross generation of electricity, while the scenario analysis is based on the final demand of electricity. Emissions factors are calculated accordingly, resulting in consistent outcomes. Final demand is used for the scenario analysis to be able to use the emission factor in other case studies.
- Emissions related to the production of solar PV panels and wind turbines are not included, but based on the potential avoided emissions calculations, these are considered to be negligible (< 10%) compared to the use phase emission reduction.

Results

Figure 15 shows the development of emissions for electricity in the reference scenario and the mitigation scenario. Additional emission reductions compared to the reference scenario are enabled by electricity demand reductions and, most importantly, decarbonisation of the electricity mix. Besides wind and solar power, decarbonisation is achieved by the deployment of bioenergy, geothermal energy, hydro energy as well as nuclear energy. A higher share of renewable energy as a result of additional wind and solar power in the electricity mix contributes to over 1200 $MtCO_2e$ in the mitigation scenario.

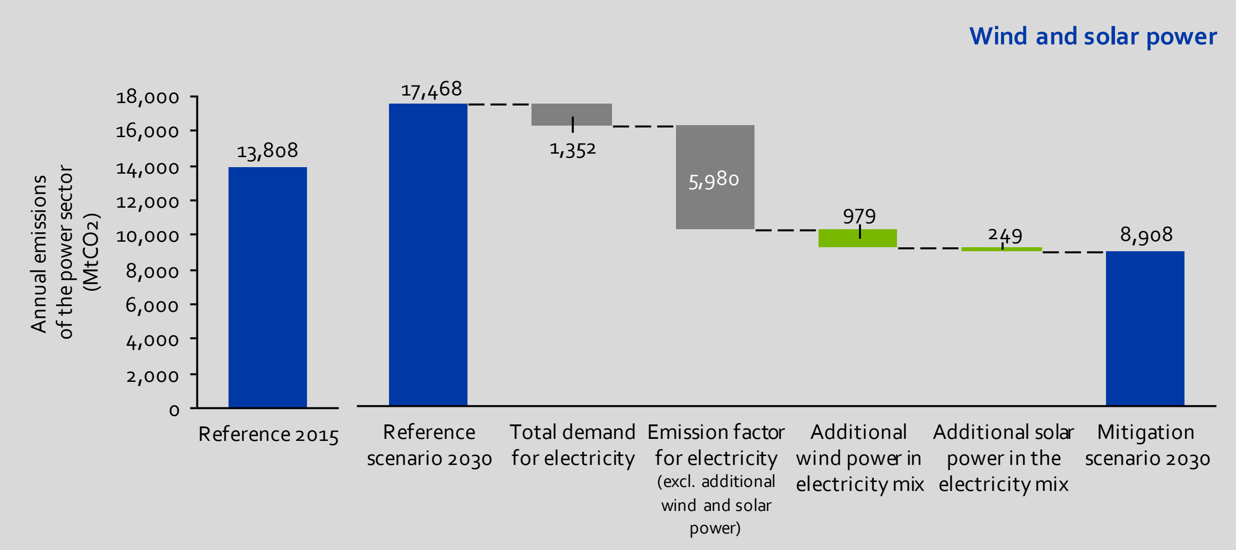

Figure 15. Annual avoided emissions from additional wind and solar power in the mitigation scenario in 2030. Source: Ecofys analysis based on ETP scenarios.

5.2.4 References

IEA, 2012. World Energy Balance 2012.

IEA, 2014. CO_2 Emissions from fuel Combustion.

IEA, 2015. Energy Technology Perspectives.

OECD/IEA, 2015. World Energy Outlook.

NREL, 2012. Life Cycle Assessment Harmonization Results and Findings. Available at: http://www.nrel.gov/analysis/sustain_lca_results.html

5.3 Efficient building envelopes

5.3.1 Contribution of chemical industry

The buildings sector is the largest contributor to global GHG emissions, accounting for about one-third of global energy end use. Chemically-based building products (insulation, piping, air barriers and sealing materials) have a significant role to play in achieving substantial reductions in energy use and associated GHG emissions by improving the energy performance of new and existing buildings. In an uninsulated home, the largest share of the heat is lost through the building envelope (walls, roof, and windows) (IEA, 2013). Therefore, insulating the building envelope is one of the most effective ways to save energy and thereby reduce CO_2 emissions. The chemical industry contributes to deep renovation through the production of insulation materials like expanded polystyrene (EPS) and polyurethane (PUR).

5.3.2 Avoided emissions potential calculation

Functional unit

The selected functional unit is heating residential buildings in China, the European Union, Japan, the Russian Federation, the United States and the world total, at an average room temperature of 18°C in 2012 (reference year). The amount of heat to maintain a house at 18°C can be reduced through the use of insulation materials. The avoided emissions are calculated by the difference in life cycle GHG emissions for insulated houses using products that are (partly) produced by the chemical industry and the baseline (currently implemented technologies). Energy consumption for cooling is not included in the functional unit. It is expected that insulation will also reduce the energy requirements for cooling.

Solutions to compare

Three solutions to compare are analysed (Table 12). The study calculates the already realized avoided emissions by comparing the market average (current insulation levels) with the reference situation of no insulation. The maximum potential for avoided emissions is calculated by comparing the maximum possible implementation of insulation with the current implementation of insulation in the market. In comparing each of the solutions, it is assumed that the same user benefit is fulfilled (i.e. maintaining the room temperature at a certain temperature). The various levels of insulation will be quantified in the next sections.

Table 12. Solutions to compare.

Solutions	Explanation
No implementation of insulation	This represents a hypothetical situation without any insulation.
Current implementation of insulation	This represents the present situation with current insulation levels.
Maximum implementation of insulation	This represents a hypothetical situation with extensive insulation.

Calculation sequence and key sources

This section first provides a brief introduction to the simplified calculation methodology applied, in relation to the credibility of the end results. Second, the simplified calculation methodology is described step by step, together with a description of data input sources and assumptions.

A simplified calculation methodology enables the calculation of worldwide and region-specific potential avoided emissions by insulation. Avoided emissions are calculated by the difference in the life cycle GHG emissions between the three solutions to compare. Emissions during production, use and end-of-life make up the total life cycle GHG emissions of insulation as part of heating residential buildings. It is known that the use phase, due to the combustion of heating fuels, contributes up to 95% to total GHG emissions of the functional unit, i.e. heating a residential building (ICCA/BASF SE, 2015; Ecofys/IEE Japan, 2015; IEA, 2012).

Emissions during the use phase are calculated by the difference in U-value between the three solutions to compare. The U-value describes the thermal transmittance of a surface, i.e. the amount of heat that is lost per square meter and per unit of temperature difference (W/m^2K). Many different factors, as modernization rate, building typology, climate zones, use of chemical and non-chemical insulation materials, will influence the U-value of an average residential building in the regions studied. Given the scope of the current analysis to provide global potential levels at an aggregated, non-specific level of analyses, typical U-values for the three solutions to compare were assumed. The assumed difference in U-value between the current and maximal implementation scenario represents an ambitious renovation case, resulting in a reduction in energy demand of over 75% for the world. In reality the effect of building insulation on the energy demand reduction is in the range of 30% to 80% (IEE Japan/Ecofys, 2015; IEA, 2012). In order to come to credible end results, a sensitivity analysis is performed based on the range in energy demand reduction. Besides the sensitivity to the degree of insulation, there is also an uncertainty about the amount of insulation material required. Given the limited contribution to the life cycle GHG emissions, these calculations are based on rough assumptions (e.g. for the floor to surface ratio) and no sensitivity analysis is applied. The uncertainties and mitigation measures described above are summarized in Table 13.

Table 13. Uncertainties per life cycle phase and related mitigation measures.

Phase	Contribution to total emissions	Key parameters	Mitigation
Production and End-of-Life	~ 5%	Amount of insulation material	Mitigation is mainly focused on the use phase since the production and end-of-life phases have only a very limited effect on the end result.
Use	~ 95%	Difference in U-values between no implementation, current implementation and maximum implementation	A range in U-values is incorporated in the study, which leads to a range in reduction potential of 30% to 80%. This range is applied to investigate the uncertainty in both the U-value of the current implementation and the maximum implementation.

The calculation sequence for insulation is as follows:

- Calculation of the building surface.
- Calculation of the theoretical energy consumption for the *current implementation* of insulation materials using the average U-values and heating efficiencies in the various regions.
- Consistency check of the theoretical energy consumption for the *current implementation* with energy consumption statistics to determine the correction factor that need to be applied to correct the theoretical energy consumption. This correction factor is required because there is always a mismatch between simplified bottom up calculations and top down statistics. These discrepancies come amongst others from different heating behaviour (heating only certain parts of the house, heating at lower or higher temperatures), simplifications in U-value calculations, distribution in heating degree days, etc.
- Calculation of the energy consumption and related emissions for the *no implementation, current implementation and maximum implementation of* solutions.
- Calculation of the insulation material requirements and related emissions for the *no implementation, current implementation and maximum implementation of* solutions.

The key parameters used for the analysis are provided in Table 14. The use of these key parameters in the various calculation steps are described below. The regions considered are China, the European Union, Japan, the Russian Federation, the United States and the whole world. The whole world ("World total") includes the regions mentioned before and the rest of the world.

Table 14. Key parameters in insulation calculations.

Parameter	Unit	China	European Union	Japan	Russian Federation	US	World total[i]
Floor area[a]	billion m^2	29.8	20.4	5.3	4.4	14.4	151
Surface-to-floor ratio[b]		1.8	1.9	2.0	1.9	2.1	1.9
U-value *no implementation*[c]	W/m^2K	2.0					
U-value *current implementation*[d]	W/m^2K	1.5	1.5	1.5	1.3	1.8	1.5
U-value *maximum implementation*[e]	W/m^2K	0.4					
Heating degree days[f]	HDD	2,283	2,976	2,389	5,560	2,406	2,000
Heating system efficiency[g]	%	74%	101%	210%	75%	80%	70%
Statistical energy consumption for space heating[h]	TWh	741	2,212	291	1,129	2,091	7,500

[a] China, EU, Japan, Russian Federation and US are based on unpublished data used for Ecofys/IEE Japan (2015); World is based on the GLOBUS Model by Schimschar (2015).

[b] Surface-to-floor ratio is determined based on the share of single family homes and apartments in WBSCD (2009), combined with expert estimate of the surface-to-floor ratio for single family homes (2.3x) and apartments (1.1x). The surface-to-floor ratio does not cover differences in average building size in the various countries.

[c] Expert estimate of house without insulation material, in reality this will differ per region depending on the materials used for the construction of the building.

[d] Expert estimate based on U-values for roofs, walls and windows for various countries and regions. Amongst others based on internal data for Europe, "Building Energy Efficiency Standards in China: Fundamentals" by Rong Li for China; "Country report on building codes in Japan 2009" by Evans, Shui, Takagi for Japan; and "Energy saving potentials of Moscow apartment buildings in residential districts" by Paiho et al. for the Russian Federation.

[e] Expert estimate, based assumptions of ambitious U-values for roofs (0.2 W/m^{2}K), walls (0.33 W/m^{2}K) and windows (2 W/m^{2}K), which is in line with ICCA (2012) and IEA (2013).

[f] China, EU, Japan, Russian Federation and US are based Ecofys/IEE Japan (2015); world is rough assumption, but will have limited effect as result of calibration with statistical energy consumption.

[g] Based on unpublished data used for EC (2015). The efficiency can exceed 100% as result of using heat pumps. Especially in Japan the share of heat pumps is high, resulting in heating system efficiencies of 210%.

[h] China, EU, Japan, Russian Federation and US are based on unpublished data used for Ecofys/IEE Japan (2015); World is estimated based on the residential energy consumption for space heating from the ETP scenarios (IEA, 2015).

[i] Unless stated otherwise, values for the world are rough expert estimates.

Calculation of building surface – The total insulation surface of existing building stock is calculated by multiplying the total residential floor area for each of the regions with the surface-to-floor ratio. Since in reality not all components of a house are insulated with insulation materials of identical properties and thickness, this simplified approach results in an uncertainty of the insulation material used. Since the limitation is only relevant for the calculation of the amount of insulation material needed, not for the use phase and therefore the impact on the total calculation is limited. Table 15 gives a summary of the calculated insulation surface for the four different regions.

Table 15. Calculation of building surface area.

Parameter	Unit	China	European Union	Japan	Russian Federation	US	World total
Floor area	billion m^2	29.8	20.4	5.3	4.4	14.4	151
Surface-to-floor ratio	-	1.85	1.86	1.96	1.91	2.14	1.91
Surface area	**billion m^2**	**55.1**	**38.1**	**10.4**	**8.4**	**30.7**	**289**

Calculation of theoretical energy consumption using the average U-values and heating efficiencies in the various regions – The theoretical energy consumption is determined by the energy required to provide the heat that is lost. Heat losses are calculated by multiplying the U-value with the insulation area, resulting in the specific heat loss (W/K). Annual energy requirements in kWh are subsequently calculated using the heating degree days and the heating system efficiency.[38] The theoretical energy consumption is provided in Table 16.

Table 16. Calculation of theoretical heat losses.

Parameter	Unit	China	European Union	Japan	Russian Federation	US	World total
Surface area	billion m^2	55.1	38.1	10.4	8.4	30.7	289
U-value *no implementation*	W/m^2K	2.0					
U-value *current implementation*	W/m^2K	1.5	1.5	1.5	1.3	1.8	1.5
U-value *maximum implementation*	W/m^2K	0.4					
Heating degree days	HDD	2,283	2,976	2,389	5,560	2,406	2,000
Heating system efficiency	%	74%	101%	210%	75%	80%	70%
Theoretical energy consumption *no implementation*	TWh	8,173	5,397	568	2,969	4,410	39,683
Theoretical energy consumption *current implementation*	TWh	5,941	3,967	417	1,853	3,890	29,763
Theoretical energy consumption *maximum implementation*	TWh	1,635	1,079	114	594	882	7,937

Consistency check of current implementation with energy consumption statistics to determine the correction factor that need to be applied to correct the theoretical energy consumption – The calculation described above is a theoretical approach. In reality large differences occur between theoretical (calculated) energy consumption and the actual (measured) consumed energy (see Table 17). The large gap between calculation and measurement can be explained by a multitude of parameters. First of all, the theoretical approach describes the ideal building, without considering ventilation, internal heat sources (people, electronic devices), effects of wind, heat from irradiation, etc. It also corrects for deviations in the assumptions made. Furthermore, in the theoretical calculation it is assumed that the whole building is always heated to 18 degrees Celsius. In reality, this is largely dependent on behaviour (heating only parts of the building, heating at higher or lower temperatures) or even energy poverty

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[38] Theoretical energy consumption (kWh) = specific heat loss (W/K) · 24 · heating degree days / heating system efficiency / 1000

(not having enough money to heat the building at the desired temperature). Heat poverty could explain the large difference in theoretical and statistical energy consumption for space heating in China.

Since using theoretical heat losses will result in overestimating avoided emissions, correction factors for the theoretical heat losses are derived based on the statistics of current residential energy consumption for space heating (Table 17). The correction factors are applied to the theoretical heat losses for the no implementation of insulation and maximum implementation of insulation scenarios given in Table 16. For the current implementation scenario, the statistical value from Table 14 is used directly.

Table 17. Comparison of theoretical energy consumption with energy consumption from statistics for residential buildings.

Parameter	Unit	China	European Union	Japan	Russian Federation	US	World total
Theoretical energy consumption *current implementation*	TWh	5,941	3,967	417	1,853	3,890	29,763
Statistical energy consumption for space heating	TWh	741	2,212	291	1,129	2,091	7,500
Correction factor	**-**	**8.0**	**1.8**	**1.4**	**1.6**	**1.9**	**4.0**

Calculation of the energy consumption and emissions for the no implementation, current implementation and maximum implementation of solutions – The emissions in the use phase are calculated based on the corrected energy consumption and a weighted average emission factor calculated based on the energy mix that is used for space heating in various countries (Ecofys/IEE Japan, 2015) and the emission factors provided in Table 2 and Table 3. Region specific energy mix characteristics (e.g. use of natural gas, electricity or district heating) result in weighted average emission factors ranging from 0.228 to 0.394 $MtCO_2e/TWh$. The emission factor of the world is based on the emission factor calculated in the scenario analysis in Section 5.3.3. It should be noted that insulation generally results in changes in behaviour, like heating to higher temperatures and heating larger areas (rebound effects), which is not accounted for.

Table 18. Calculation of use phase emissions.

Parameter	Unit	China	European Union	Japan	Russian Federation	US	World total
Theoretical energy consumption *no implementation*	TWh	8,173	5,397	568	2,969	4,410	39,683
Theoretical energy consumption *current implementation*	TWh	5,941	3,967	417	1,853	3,890	29,763
Theoretical energy consumption *maximum implementation*	TWh	1,635	1,079	114	594	882	7,937

Parameter	Unit	China	European Union	Japan	Russian Federation	US	World total
Corrected energy consumption *no implementation*	TWh	1,020	3,010	397	1,809	2,371	10,000
Statistical energy consumption *current implementation*	TWh	741	2,212	291	1,129	2,091	7,500
Corrected energy consumption *maximum implementation*	TWh	204	602	79	362	474	2,200
Weighted average emission factor	$MtCO_2$/ TWh	0.393	0.228	0.361	0.290	0.394	0.220
Use phase emissions *no implementation*	$MtCO_2$	401	686	143	525	935	2,200
Use phase emissions *current implementation*	$MtCO_2$	292	504	105	328	825	1,650
Use phase emissions *maximum implementation*	$MtCO_2$	80	137	29	105	187	440

Calculation of the insulation material required for the no implementation, current implementation and maximum implementation of solutions.

The emissions from the production and end-of-life of the insulation materials are calculated based on the required amount of insulation material and the emission factors for production and end-of-life (Table 19). The volume of insulation material is determined by calculating the required thickness to achieve a certain U-value. The production amount is then calculated by multiplying the surface with the thickness and the density of the insulation materials. Calculations are simplified by only considering EPS, chemically derived thermal insulator, as insulation material. A further simplification concerns the calculation of the insulation thickness: the material the wall is made of was not considered, whereas in reality this influences the insulation thickness. Since this parameter (insulation thickness) only influences the emissions related to the production and the end-of-life phase of the insulation material, it is not significant for the final outcomes, which are determined by the use phase emissions.

The emissions from the production and end-of-life of the insulation material are calculated by: amount of insulation · (emission factor production + emission factor end-of-life) / lifetime insulation material.

Table 19. Parameters for calculation of amount of insulation material.

Parameter	Unit	Value	Source
Thermal conductivity EPS	W/mK	0.036	Expert estimate
Thickness EPS for U = 2.0 W/m^2K	m	0.000	Calculated
Thickness EPS for U = 1.47 W/m^2K	m	0.007	Calculated

Thickness EPS for U = 0.35 W/m²K	m	0.072	Calculated
Density EPS	kg/m³	17	ECO, 2011; density ranges from 13-17 kg/m³, conservative assumption
Emission factor EPS production	kgCO₂e/kg EPS	2.9	ECO, 2011
Emission factor EPS end-of-Life	kgCO₂e/kg EPS	3.4	ECO, 2011
Lifetime EPS	y	40	Expert estimate

Table 20. Calculation of the amount of insulation material and associated GHG emissions.

Parameter	Unit	China	European Union	Japan	Russian Federation	US	World total
Insulated surface	billion m²	**55.1**	**38.1**	**10.4**	**8.4**	**30.7**	**289**
No implementation							
Amount	billion kg	0.0	0.0	0.0	0.0	0.0	0.0
Annualised emissions	MtCO₂e	0.0	0.0	0.0	0.0	0.0	0.0
Current implementation							
Amount	billion kg	5.6	4.2	1.1	1.5	1.3	29.5
Annualised emissions	MtCO₂e	0.9	0.7	0.2	0.2	0.2	4.6
Maximum implementation							
Amount	billion kg	67.4	46.6	12.7	10.3	37.6	354.2
Annualised emissions	MtCO₂e	10.6	7.3	2.0	1.6	5.9	55.7

Dealing with uncertainty

As described in the introduction to the calculation methodology, many different factors, as modernization rate, building typology, climate zones, use of chemical and non-chemical insulation materials, applied thickness of insulation materials and regional insulation standards will influence the U-value of an average residential building in the regions studied. The assumed difference in U-value between the current and maximal implementation scenario represents an ambitious renovation case, resulting in a reduction in energy demand of over 75% for the world. In reality the effect of building insulation is in the range of 30% to 80% (IEE Japan/Ecofys, 2015; IEA, 2012). In order to come to credible end results, a sensitivity analysis is performed based on the range in energy demand reduction. From this sensitivity analysis, it can be concluded that the avoided emissions potential ranges 0.5-1.3 GtCO₂e.

Results

Retrofitting the full current worldwide residential building stock using insulation material (maximum implementation) would result in annual emission reductions of 1.2 $GtCO_2e$, which represents a reduction of over 70% in the current emissions related to building heating of the residential building stock in the world (reference year 2012). The avoided emissions potential is in large part determined by the actual energy demand reduction through insulation, which varies on average from 30% to 80%. Given the uncertainty in the actual energy demand reductions through insulation, the avoided emission potential ranges from 0.5 to 1.3 $GtCO_2e$. Besides avoided emissions from energy demand reductions for space heating, additional energy savings can be expected from savings in cooling requirements during warm seasons.

Avoided emissions from insulation in the residential building sector are dominated by the reduction in heating fuel consumption during the use phase; the emissions related to the production of the insulation material are marginal compared to the avoided emissions during the use phase.

Table 21. Annual (avoided) emissions for insulation.

Solution to compare	Emissions (MtCO2e)					
	China	European Union	Japan	Russian Federation	US	World total
Annual emissions - No implementation of insulation	401	686	143	525	935	2,200
Annual emissions - Current implementation of insulation	292	505	105	328	825	1,655
Annual emissions - Maximum implementation of insulation	91	144	31	107	193	496
Annual realised avoided emissions – Current implementation level	109	181	38	197	110	545
Annual avoided emissions potential – Maximum implementation level	202	360	75	221	632	1,159

Insulation

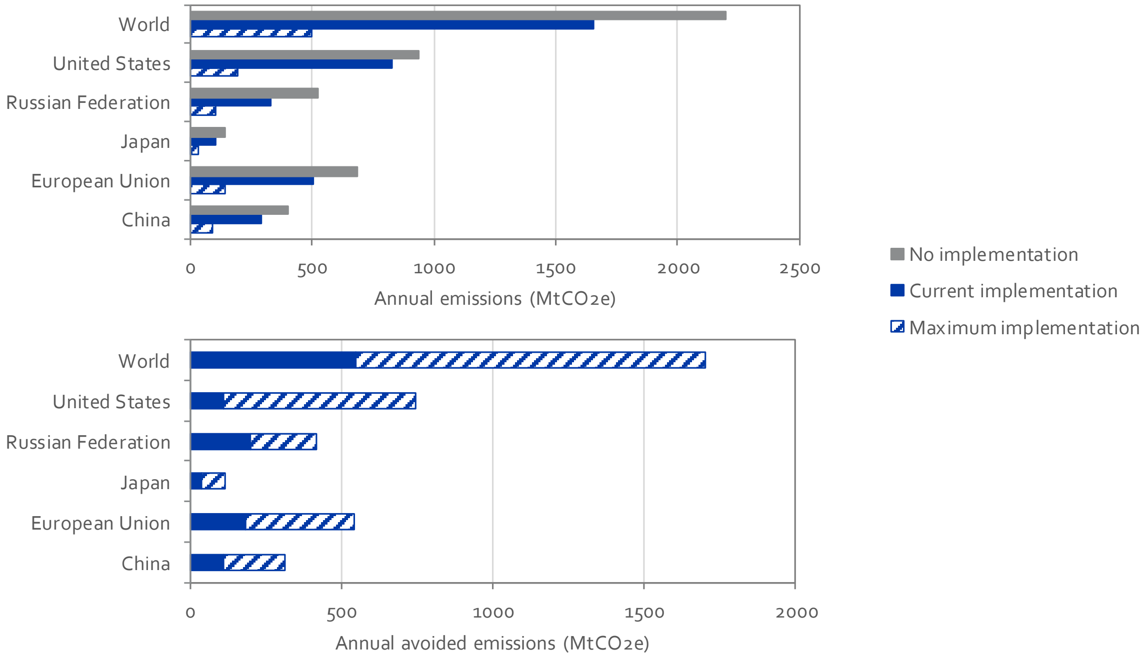

Figure 16. Annual (avoided) emissions for building insulation in the residential sector. First graph shows the emissions related to space heating, the second graph shows the realized and potential annual avoided emissions as a result of insulation.

5.3.3 Scenario analysis

In the scenario analysis the contribution of efficient building envelopes in reaching the mitigation scenario is investigated. In the following sections we discuss the scenario parameters, differences between the potential avoided emissions calculation and the scenario analysis, as well as the results of the scenario analysis. Given the limited information on separate parameters in the ETP 2015 scenarios, it is not possible to parameterize the calculation described above. Therefore, a simplified scenario analysis is performed, investigating the impact of the combined effect of efficient building envelopes and heating technology energy efficiency, as well as the effect of a reduction of the carbon intensity of space heating: *emissions for space heating = demand for space heating · carbon intensity for space heating.* Heat loss in building is caused by heat losses through walls, floors and roofs (about 50%), through infiltration (about 25%) and through windows (about 25%) (Huang et al, 1999). While deep renovation focusses on all these elements, largest part of the energy savings can be related to improvements of building insulation.

Parameters

For the scenario analysis we make use of the demand for space heating in the residential sector from the ETP 2015 scenarios. In the ETP 2015 building tables, only the direct emissions for space heating are reported. Indirect emissions for space heating are calculated based on the demand for electricity and heat and the emission factors for electricity and heat.

To calculate the difference between the reference scenario and the mitigation scenario (blue bars) all relevant parameters from the calculation above are updated according to the scenario quantification (Table 23). The breakdown of the various factors (grey bars) is calculated using a decomposition analysis. In the decomposition analysis only one parameter is changed to investigate the impact of that single parameter. The results of the individual steps in the decomposition analysis are subsequently normalized in proportion to their relative non-normalized contribution to yield the overall emission reduction. The decomposition formula is provided in Section 5.10.2.

Table 22. Source and calculation methodology for scenario parameters for the insulation case study.

Scenario parameter	Source
Total demand for residential space heating	Obtained directly from the ETP 2015 buildings tables.
Carbon intensity for space heating	Calculated using *(direct emissions from residential space heating + indirect emissions from residential space heating) / total demand for residential space heating*. Direct emissions from space heating and total demand for space heating are obtained directly from the ETP 2015 building tables. Indirect emissions for space heating are calculated using *(electricity demand for residential space heating * emission factor for electricity) + (commercial heat demand for residential space heating * emission factor for heat).* Demand for electricity and demand for heat are directly obtained from the ETP 2015 building tables. Emission factor for electricity is determined in the electricity from wind and solar power case study. The emission factor for heat is analysed based on ETP 2015 figure 1.26 and 1.28, together with the emission factor determined in the electricity from wind and solar power case study. First the electricity and heat demand is obtained from ETP 2015 figure 1.26. Subsequently, the total indirect emissions are obtained from ETP 2015 figure 1.28. Based on the emission factor for electricity, the emissions from electricity are calculated. The remaining indirect emissions are allocated to heat, based on which the emission factor for heat is calculated.

Table 23. Quantification of scenario parameters for the insulation case study.

Parameter	Unit	2015	2030	
		Reference	Reference	Mitigation
Total demand for residential space heating	TWh	7,675	8,840	7,596
Total direct emissions from residential space heating	$MtCO_2$	983	1,052	702
Electricity demand for residential space heating	PJ	2,006	2,912	3,832
Commercial heat demand for residential space heating	PJ	4,399	6,081	5,852
Emission factor for heat	$MtCO_2/TWh$	0.279	0.284	0.215

Parameter	Unit	2015	2030	
		Reference	Reference	Mitigation
Total indirect emissions from residential space heating	$MtCO_2$	709	954	699
Carbon intensity for space heating	$MtCO_2$/TWh	0.220	0.227	0.184

Discussion of major differences between avoided emissions potential calculation and scenario analysis

- The base year in the avoided emissions potential calculation (2012) is different from the base year in the scenario analysis calculation (2015) resulting in slightly different values for the key parameters.
- Both the avoided emissions potential calculation and the scenario analysis focus on the residential sector. Also in the public and commercial services sector substantial savings are expected.
- The scenario analysis and the potential avoided emissions calculation rely on fundamentally different methodologies. The potential avoided emissions were derived from a bottom-up approach using basic input parameters. The scenario analysis was bound to the ETP modelling framework, which already provided information on avoided emissions in the buildings sector. Therefore the analysis focused on a top-down approach to quantify the levers of the avoidance. Each approach has individual limitations, e.g. significant uncertainties in the bottom-up assessment, or limited data access for the root-cause analysis in the scenarios.
- Emissions related to the production of insulation materials are not included, but on the basis of the potential avoided emissions calculations, these are considered to be negligible (< 5%) compared to the use phase emission reduction.
- The carbon intensity of space heating determined based on the ETP scenarios represent the emission factor for heat in general, including industrial heat consumption. The ETP scenarios do not provide sufficient information to determine an emission factor for residential space heating only.

Results

Figure 17 shows the development of emissions for residential space heating in the reference scenario and the mitigation scenario. Additional emission reductions compared to the reference scenario are enabled by building envelope improvements and energy efficiency, as well as a reduction in the carbon intensity for space heating. The annual emission reduction from additional efficient building envelopes including additional insulation in the mitigation scenario will amount to over 250 $MtCO_2e$ in 2030. In addition, improving the energy efficiency of buildings has a lot of co-benefits beyond climate change mitigation, such as increased comfort levels.

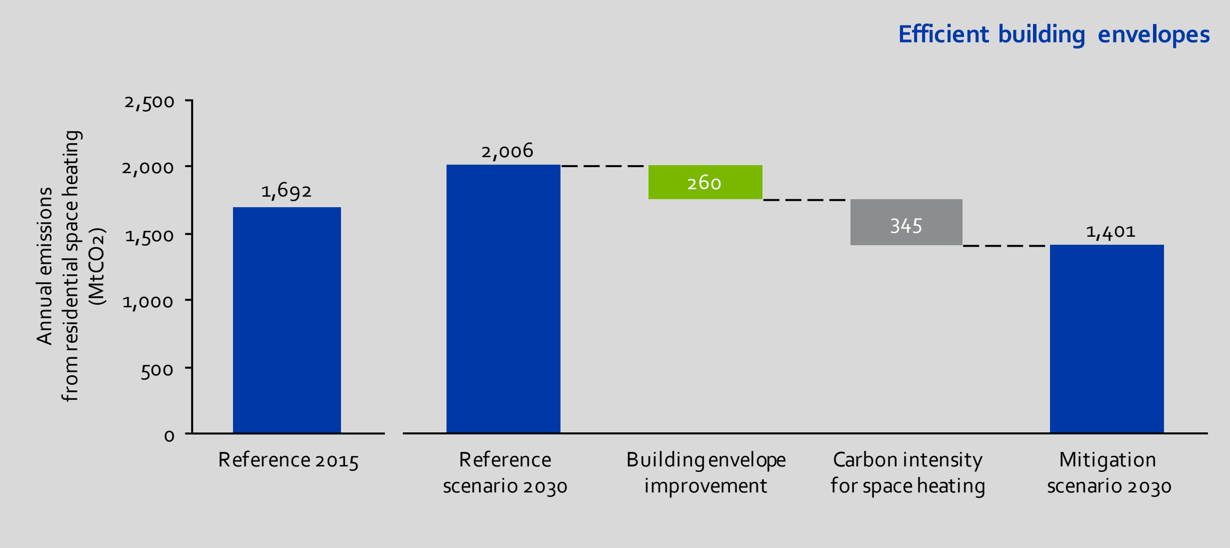

Figure 17. Annual avoided emissions from additional efficient building envelopes in the mitigation scenario in 2030. Source: Ecofys analysis based on ETP scenarios.

5.3.4 References

EC, 2015. Savings and benefits of global regulations for energy efficient products: A 'cost of non-world' study. Available at: https://ec.europa.eu/energy/sites/ener/files/documents/Cost%20of%20Non-World%20-%20Final%20Report.pdf

ECO, 2011. Environmental Product Declaration, Expanded Polystyrene (EPS) Foam Insulation. Available at: http://www.atermit.com/sites/default/files/ECO-EPS-00010101-1106_Density%20_5kg_Wh_v2.pdf

Ecofys/IEE Japan, 2015. Development of sectoral indicators for determining potential decarbonisation opportunity. Available at: http://www.ecofys.com/files/files/ieej-ecofys-2015-development-of-sectoral-indicators.pdf

Huang, Hanford and Yang, 1999. Residential Heating and Cooling Loads Component analysis. Available at: http://simulationresearch.lbl.gov/dirpubs/44636.pdf

ICCA/BASF SE, 2015. Case study: External Thermal Insulation Composite System (ETICS) for the refurbishment of an existing detached house in Germany. Available at: http://www.icca-chem.org/Public/Avoided%20Emissions%20Case%20Studies/Case%20study%204%20-%20Avoided%20Emissions%20Guideline%20-%20%20BASF.pdf

ICCA, 2012. Building Technology Roadmap. Available at: http://www.icca-chem.org/ICCADocs/Building%20Technology%20Roadmap%20-%20Report.pdf

IEA, 2012. World Energy Balance 2012.

IEA, 2013. Technology Roadmap: Energy efficient building envelopes. Available at: https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapEnergyEfficientBuildingEnvelopes.pdf

IEA, 2015. Energy Technology Perspectives.

Schimschar, 2015. Energy- and emission reductions in the global building stock. Unpublished doctoral thesis. University of Utrecht, Utrecht.

WBCSD, 2009. Energy Efficiency in Buildings: Transforming the Market. Available at: http://www.wbcsd.org/transformingthemarketeeb.aspx

5.4 Efficient lighting

5.4.1 Contribution of chemical industry

Substantial opportunities exist to improve the energy efficiency of appliances in buildings. LED light bulbs are new and highly energy efficient light bulbs, that have a much higher luminous efficiency than conventional light bulbs such as incandescent bulbs and halogen bulbs. The energy efficiency potential of LED light bulbs is up to 80% compared to what is currently applied in the market. Chemical products, such as semiconductor gas, phosphor, substrates, and sealant, are essential materials to enable high energy efficiency, reliability, and long life of LED light bulbs.

5.4.2 Avoided emissions potential calculation

Functional unit

The selected functional unit is providing worldwide lighting in the residential and commercial & industry sector in 2010 (reference year). This functional unit represents 125,934,044 billion lumen hours per year, of which 21% occurs in the residential sector. The functional unit is calculated based on the installed stock of lamps in 2010, average wattage and lighting hours from UNEP (2012), complemented with assumptions on the luminous efficiency and life time per lighting type. Lighting types considered are incandescent lamps (GLS), tungsten halogen lamps (HAL), compact fluorescent lamps (CFL), light emitting diodes lamps (LED), high intensity discharge lamps (HID) and linear fluorescent lamps (FL). The potential avoided emissions are calculated by the difference in life cycle GHG emissions from lighting with the current mix of lighting types and from lighting with efficient LED only.

Solutions to compare

Four solutions to compare are analysed (Table 24). To determine the realized potential in 2010, the *current implementation* is compared to the hypothetical situation of *no implementation* of LED lighting. To determine the potential avoided emissions, the *maximum implementation* of LED lighting is compared to the *current implementation.* According to the ICCA & WBCSD guidelines (2013) “solutions to be compared shall be distributed/used on the market, and not in the process of being banned, in the reference time period and geographic region.” While incandescent lighting was used on the market in the reference period, many countries are currently in the process of phasing out (certain types of) incandescent lighting. Therefore, a fourth solution, representing phasing out of incandescent lighting, is added to illustrate the potential of LED lighting compared to a situation where incandescent lighting is phased out. Figure 18 and Figure 19 show the global market shares (based on amount of light provided) of the six lighting types considered in the four solutions to compare.

Table 24. Solutions to compare for lighting.

Solutions	Explanation
No implementation of LED	This represents a hypothetical 2010 situation without LED lighting. LED lighting in the 2010 stock is replaced by the other lamp types based on market share.
Current implementation of LED	This is the present market average situation in 2010.
Phasing out incandescent light bulbs*	This represents a hypothetical 2010 situation without incandescent lighting. Incandescent lighting in the 2010 stock is replaced by the other lamp types, excluding LED, based on market share.
Maximum implementation of LED	In this situation the entire stock is replaced by efficient LED lighting.

* According to the ICCA & WBCSD guidelines (2013) "solutions to be compared shall be distributed/used on the market, and not in the process of being banned, in the reference time period and geographic region." Since incandescent lighting is currently (partly) banned, the *Phasing out incandescent light bulbs* is considered as additional solution to compare to illustrate the effect of a ban on incandescent lighting.

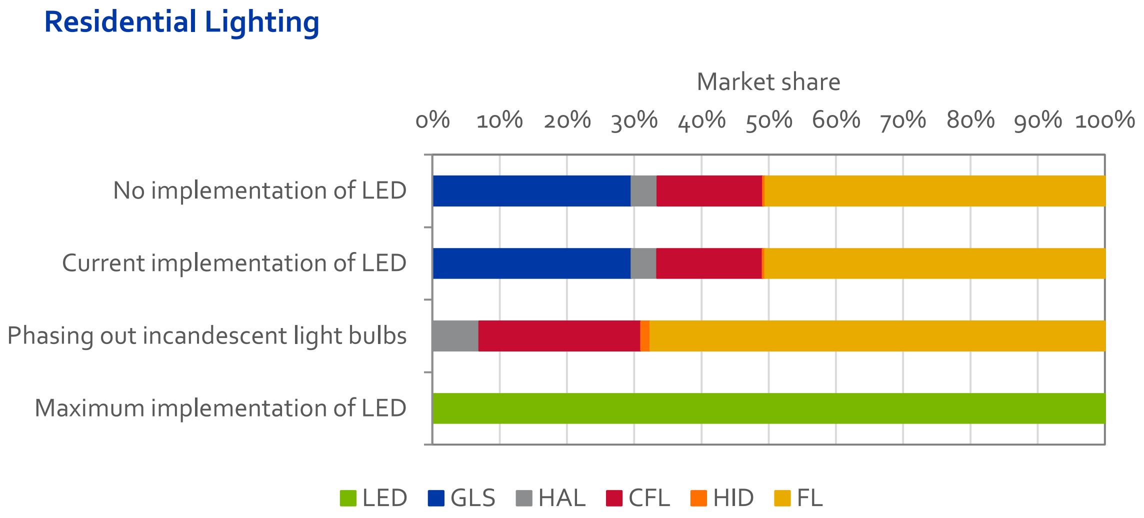

Figure 18. Global market shares of lamp types in solutions to compare (Residential Lighting). Calculated based on UNEP (2012). The share of LED in the current implementation is only 0.2% and therefore not visible in the figure.

Commercial/Industrial Lighting

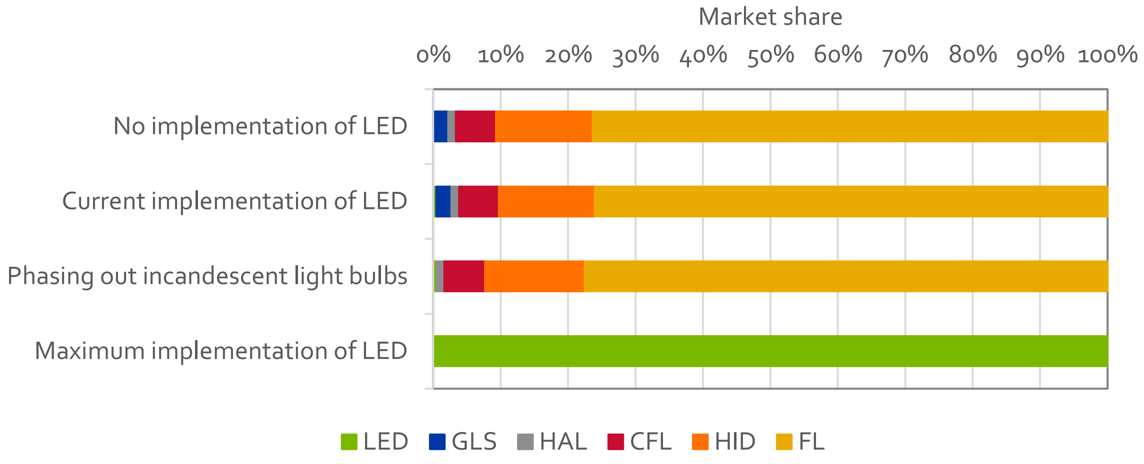

Figure 19. Global market shares of lamp types in solutions to compare (Commercial & Industrial Lighting). Calculated based on UNEP (2012). The share of LED in the current implementation is only 0.2% and therefore not visible in the figure.

Calculation sequence and key sources

The avoided emissions are calculated by the difference in the life cycle GHG emissions associated with providing lighting for one year. Total GHG emissions per solution to compare are calculated as follows:

- Production and end-of-life phase:
  - Market shares per lighting type are determined per solution to compare.
  - The amount of lamps needed to provide the lighting is determined by dividing the total burning hours per lamp type by the life time of the lamp type.
  - The emissions are calculated by multiplying the number of lamps with the emissions factors for the production and end-of-life phases.
- Use phase:
  - Lighting demand per lamp type is calculated by multiplying the market share per lamp type with the total lighting demand (functional unit).
  - The electricity demand per lamp type is calculated by dividing the lighting demand by the luminous efficiency
  - The emission factor of electricity is a combination of a country specific emission factor for the direct emissions, combined with a general factor to account for the full life cycle.
  - The use phase emissions are calculated by multiplying the electricity demand by the country-specific emission factor
- The realized and potential avoided emissions are determined by the difference in the life cycle GHG emissions between the solutions to compare.

Input data sources and assumptions

The following data were taken on a country level from UNEP (2012), both for residential and commercial & industrial lighting:

- Installed stock of lamps in 2010 per lighting type.
- Average wattage per lighting type.
- Average lighting hours per lighting type.

Table 25 shows the assumptions used for the luminous efficiency and life time of the six lighting types considered. Assumptions for the luminous efficiency are based on EC (2015), IEA ECBCS (2010), JCIA (2011) and input from ICCA. Note that the luminous efficiency of LED lighting is rapidly improving and represent the current best available technology. The assumptions for the life time and the typical burning hours per year are based on UNEP (2012). Please note that the typical burning hours can be a range if the database contains different values per region.

Table 25. Luminous efficiency and life time and typical burning hours per lighting type.

Lighting type	Luminous efficiency (lm/W)*	Life time (hours)	Typical burning hours (hours/year)	Total burning hours (billion hours)
Incandescent (GLS)	15	1,000	Residential: 694-1460 Commercial: 2920	Residential: 9247 Commercial: 2089
Tungsten halogen (HAL)	20	1,300	Residential: 694-1460 Commercial: 2920	Residential: 1027 Commercial: 914
Compact fluorescent (CFL)	60	7,000	Residential: 694-1460 Commercial: 2920	Residential: 5060 Commercial: 5638
Light emitting diode (LED)*	150	17,000	Residential: 694-1460 Commercial: 2920	Residential: 25 Commercial: 210
High intensity discharge (HID)	100	9,000	Residential: 3650 Commercial: 3650	Residential: 17 Commercial: 972
Linear fluorescent (FL)	75	14,000	Residential: 913-1825 Commercial: 3650	Residential: 5109 Commercial: 23976

* It is assumed that the conversion factors from "lamp efficiency" to "luminaire efficiency" are the same for all types of lamp including LEDs (approx. 70%). This allows us to use "lamp efficiency" to directly compare emissions. It should be noted that some LED lamps such as down-light has lower conversion values as low as 50% due to their structure.

Table 26 shows the emission factors applied for the production and end-of-life treatment of the lighting types. These are based on multiple LCA studies. The values for end-of-life treatment of CFL and FL lamps are negative due to the benefit of recycling components of the lamps. Because the impacts of the production and end-of-life emissions are very limited compared to the use phase emissions (<5%), the system boundaries and approaches to treat recycling at end-of-life in the various studies have not been compared in detail. Given the small impact, differences have a negligible impact.

Table 26. Emission factors for lamp production and end-of-life.

	GLS	HAL	CFL	LED	HID	FL
Production (kgCO_2e/lamp)	0.14 (OSRAM, 2009)	0.0808 (Weltz et al., 2011)	0.88 (OSRAM, 2009)	2.4 (OSRAM, 2009)	0.67698 (Defra, 2009)	1.452 (Weltz et al., 2011)
End-of-life (kgCO_2e/lamp)	0.009 (JCIA, 2011)	0.0148 (Weltz et al., 2011)	-0.0679 (Weltz et al., 2011)	0.002 (JCIA, 2011)	0.068982 (Defra, 2009)	-0.1166 (Weltz et al., 2011)

The direct emissions of electricity consumption are based on country-specific emission factors for 2010 from IEA (2014). For countries/regions where data is not available, the non-OECD average is applied. To account for the full life cycle emissions of electricity supply, a factor of 1.19 is applied to these emissions factors. This factor is estimated based on the global average mix of fuel sources in 2010 (IEA, 2014) and the ratio between direct CO_2 emissions and total GHG emissions from Ecoinvent version 2 (2010).

Calculated parameters

Table 27, Table 28 and Table 29 show the lighting demand and market shares in 2010. These values are calculated based on the inputs above. The regions considered are the United States, Japan, the European Union, Brazil, Middle East, the rest of the world and the whole world. The whole world ("World total") includes the regions mentioned before and the rest of the world

Table 27. Lighting demand in 2010 (billion lumen-hours).

	World total	US	Japan	Europe	Brazil	Middle East	Rest of World
Residential	26,919,786	4,543,157	833,202	3,417,844	965,165	1,165,572	15,994,847
Comm. & Industrial	99,014,258	24,027,927	4,438,051	15,323,144	1,701,782	5,675,074	47,848,281
Total	125,934,044	28,571,084	5,271,253	18,740,988	2,666,947	6,840,646	63,843,128

Table 28. Market shares of residential lighting types in 2010, based on lumen-hours.

Product	Market shares residential lighting, current situation						
	World total	US	Japan	Europe	Brazil	Middle East	Rest of World
LED	0.2%	0.3%	0.3%	0.0%	0.1%	0.1%	0.2%
GLS	29.6%	49.4%	16.6%	51.7%	22.9%	26.8%	20.5%
HAL	3.8%	4.1%	2.7%	11.3%	3.8%	2.9%	2.3%
CFL	15.7%	18.1%	17.4%	12.8%	28.5%	16.4%	14.7%
HID	0.4%	0.6%	0.2%	0.0%	0.3%	0.5%	0.4%
FL	50.4%	27.6%	63.0%	24.2%	44.4%	53.3%	62.0%

Table 29. Market shares of commercial & industrial lighting types in 2010, based on lumen-hours.

Product	Market shares commercial & industrial lighting, current situation						
	World total	US	Japan	Europe	Brazil	Middle East	Rest of World
LED	0.5%	1.2%	0.2%	0.0%	0.0%	0.1%	0.4%
GLS	2.2%	1.1%	1.6%	2.5%	4.3%	1.9%	2.7%
HAL	1.1%	0.8%	1.3%	1.0%	0.9%	1.4%	1.3%
CFL	5.9%	3.2%	9.8%	4.5%	11.1%	6.4%	7.1%
HID	14.3%	12.6%	13.0%	23.3%	13.7%	13.3%	12.6%
FL	76.0%	81.1%	74.1%	68.7%	69.9%	77.0%	76.0%

Results

Global emissions related to lighting in buildings were 1.56 $GtCO_2e$ in 2010. Without the application of (the still very small share of) LED, emissions would be increased by 0.03 $GtCO_2e$ (using the 2010 average market share, but excluding LED). If the total lighting stock were LED lighting, emissions would be reduced by 0.97 $GtCO_2e$.

In comparison, replacing the 2010 stock of incandescent lighting with other lighting types excluding LED, based on the 2010 market shares, would result in emissions that are lower by 0.32 $GtCO_2e$.

Table 30. Annual (avoided) emissions for lighting in the residential and commercial & industrial sector.

Solution to compare	Emissions ($MtCO_2e$)						
	World total	US	Japan	Europe	Brazil	Middle East	Rest of world
No implementation	1,567	328	42	156	6	84	951
Current implementation	1,564	327	42	156	6	84	949
Phasing out incandescent light bulbs	1,242	249	37	115	4	69	768
Maximum implementation	597	120	18	53	2	33	371
Annual realised avoided emissions – Current implementation level	3	2	0	0	0	0	2
Annual avoided emissions potential – Maximum implementation level	967	206	24	103	4	51	579

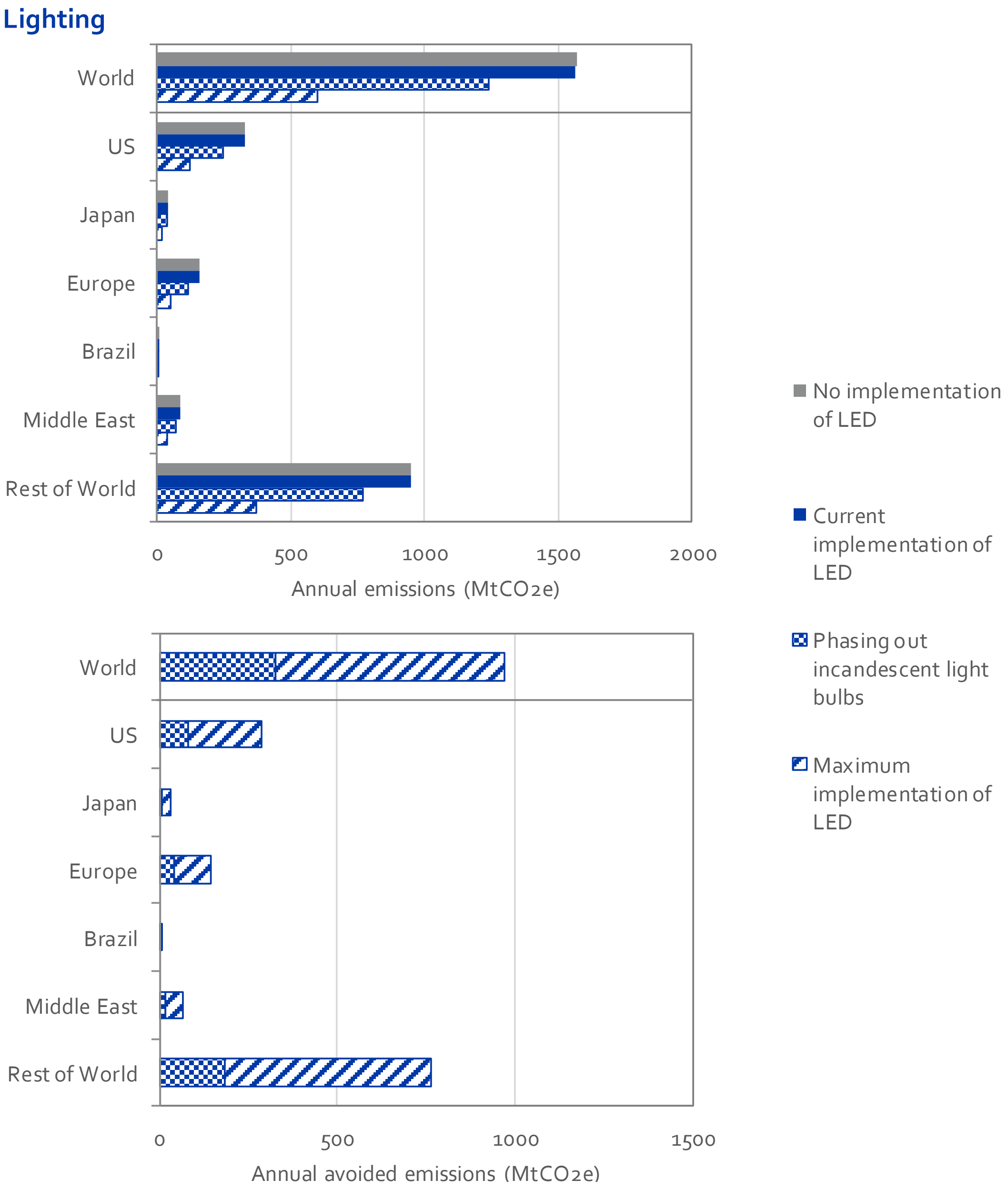

Figure 20. Annual (avoided) emissions for lighting in the residential and commercial & industrial sector. First graph shows the emissions related to lighting, the second graph shows the annual realised and potential avoided emissions. In addition, the solution *Phasing out incandescent light bulbs* is shown in the graph.

5.4.3 Scenario analysis

In the scenario analysis, the contribution of LED lighting in reaching the mitigation scenario is investigated. The following sections discuss the scenario parameters, differences between the potential avoided emissions calculation and the scenario analysis, as well as the results of the scenario analysis. The bottom-up data used in the potential avoided emissions calculation result in unrealistic results when used together with the ETP 2015 data. A slightly simplified approach is therefore applied, determining the lighting demand based on the electricity demand for lighting together with assumptions about the current efficiency of lamps.

Parameters

Emissions for lighting are calculated by multiplying *electricity demand for lighting* by *emission factor for electricity*. The electricity demand for lighting is directly obtained from the ETP 2015 building tables and the emission factor for electricity is calculated in the electricity from wind and solar power case study.

In addition, further analyses are performed to provide more insights into the role of efficient lighting. The electricity demand for lighting is split into lighting demand developments and average luminous efficiency developments: *electricity demand for lighting* is equal to *lighting demand* multiplied by *average luminous efficiency.* Using the luminous efficiency, the share of LED is determined by solving the equation $\eta_{average} = x\,\eta_{LED} + (1-x)\eta_{other\ lamps}$ for x, where $\eta_{average}$ is *average luminous efficiency*, η_{LED} is *luminous efficiency of LED*, $\eta_{Ohter\ lumps}$ is *luminous efficiency of other lumps*, and x is *market share of LED.* It is assumed that the efficiency of other lamps is constant over time.

To calculate the difference between the reference scenario and the mitigation scenario (blue bars) all relevant parameters from the calculation above are updated according to the scenario quantification (Table 32). The breakdown of the various factors (grey bars) is calculated using a decomposition analysis. In the decomposition analysis only one parameter is changed to investigate the impact of that single parameter. The results of the individual steps in the decomposition analysis are subsequently normalized in proportion to their relative non-normalized contribution to yield the overall emission reduction. The decomposition formula is provided in Section 5.10.3.

Table 31. Source and calculation methodology for scenario parameters for the lighting case study.

Scenario parameter	Source
Electricity demand for lighting	Obtained directly from the ETP 2015 building tables
Emission factor for electricity	Calculated using *emissions from power generation / total final demand for electricity*, which are obtained from the ETP 2015 electricity tables, as also done in the solar and wind power case study.
Lighting demand	The lighting demand in 2015 is calculated by multiplying *electricity demand for lighting by average luminous efficiency of lighting*. Future years are determined using the increase in floor area, assuming that the lighting demand increases

Scenario parameter	Source
	proportionally. The increase in residential floor area is determined by the number of households multiplied by average house size from the IEA, 2013 report "Transition to Sustainable Buildings. Strategies and Opportunities to 2050." The increase in services floor area is directly obtained from this report. Electricity demand for lighting in the residential and services sector are obtained directly from the ETP 2015 buildings tables. The average luminous efficiency of lighting (excluding LED) and the share of LED in 2015 is assumed to be respectively 30 lm/W and 1.2% for the residential sector and respectively 65 lm/W and 0.9% for the services sector. The market shares of LED are based on DOE, 2015.
Luminous efficiency of LED	The luminous efficiency of LED is assumed to increase for the residential sector from 94 lm/W in 2015 to 156 lm/W in 2030 and for the services sector from 106 lm/W in 2015 to 181 lm/W in 2030. This is based on DOE, 2014.
Market share of LED	For future years, the market share of LED is calculated based on the lighting demand and the electricity demand for lighting, resulting in the average luminous efficiency of lighting (see above). The market share is calculated with the following formula: (Average luminous efficiency in year X – Average luminous efficiency excluding LED in 2015)/(Luminous efficiency of LED in year X - Average luminous efficiency excluding LED in 2015), in which the average luminous efficiency is calculated by lighting demand in year X / electricity demand in year X / 1000.

Table 32. Quantification of scenario parameters for lighting case study.

Parameter	Unit	2015	2030	
		Reference	Reference	Mitigation
General				
Emission factor for electricity	$MtCO_2$/TWh	0.66	0.59	0.33
Residential				
Electricity demand for lighting	TWh	766	964	640
Residential floor area	billion m^2	183,039	229,548	229,548
Lighting demand	billion lm·h	23,570,228	29,559,252	29,559,252
Luminous efficiency of LED	lm/W	94	156	156
Market share of LED	%	1.2	0.5	12.9
Services				
Electricity demand for lighting	TWh	1,191	1,323	1,059
Services floor area	billion m^2	40,771	52,124	52,124

Parameter	Unit	2015	2030	
		Reference	Reference	Mitigation
Lighting demand	billion lm·h	77,842,274	99,519,278	99,519,278
Luminous efficiency of LED	lm/W	106	181	181
Market share of LED	%	0.9	8.8	24.9
Total				
Electricity demand for lighting	TWh	1,957	2,287	1,699
Lighting demand (total)	billion lm·h	101,412,503	130,630,341	130,630,341
Luminous efficiency of LED	lm/W	103	181	178
Market share of LED (weighted average based on lm·h)	%	1.0	6.9	22.2

Discussion of major differences between avoided emissions potential calculation and scenario analysis

- The base year in the avoided emissions potential calculation (2010) is different from the base year in the scenario analysis calculation (2015) resulting in slightly different values for the key parameters.
- The calculation method applied is slightly different from the methodology applied for the potential avoided emissions calculation. Lighting demand is now calculated based on the electricity demand for lighting from the ETP 2015 scenarios and assumptions on the average luminous efficiency.
- The luminous efficiency of other lamps is assumed to be constant over time. This means that the whole energy efficiency improvement of the lighting stock is related to LED efficiency improvements and LED market share growth. In the graph it is described as "efficient lighting".
- Emissions related to the production of LED lamps are not included, but based on the potential avoided emissions calculations, these are considered to be negligible (< 5%) compared to the use phase emission reduction.

Results

Figure 21 shows the development of emissions for lighting in the reference scenario and the mitigation scenario. Emission reductions are enabled by deployment of energy efficient lighting, such as LED lamps, as well as decarbonisation of the electricity mix. Energy efficiency improvement as a result of additional efficient lighting will contribute to an annual emission reduction of approximately 300 $MtCO_2e$ in 2030. Deployment of LED light bulbs has a lot of co-benefits beyond climate change mitigation, including a reduction of life cycle costs for lighting compared to conventional light bulbs and an improved safety compared to kerosene lighting in developing countries.

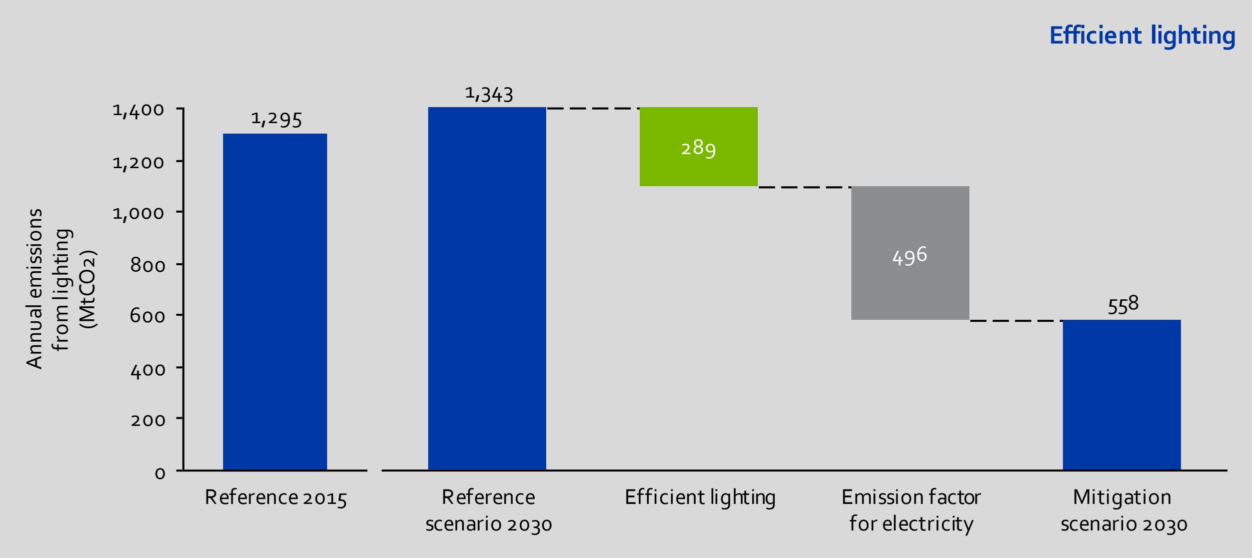

Figure 21. Avoided emissions from additional efficient lighting in the mitigation scenario in 2030. Source: Ecofys analysis based on ETP scenarios.

5.4.4 References

Defra, 2009. Life Cycle Assessment of Ultra-Efficient Lamps. Navigant Consulting Europe, Ltd. A research report completed for the Department for Environment, Food and Rural Affairs.

DOE, 2014. Energy Savings Forecoast of Solid-State Lighting in General Illumination Applications.

DOE, 2015. Adoption of Light-Emitting Diodes in Common Lighting Applications.

EC, 2015. Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements ('Lot 8/9/19'). Draft Interim Report, Task 3 (revision 1). Use of Light Sources. Prepared for the European Commission by VHK, in cooperation with VITO and JeffCott Associates.

Ecoinvent, 2010. Ecoinvent Database version 2.2. Swiss centre for Live Cycle Inventories.

ICCA/WBCSD, 2013. Addressing the Avoided Emissions Challenge: Guidelines from the chemical industry for accounting for and reporting greenhouse gas (GHG) emissions avoided along the value chain based on comparative studies. Available at: http://www.icca-chem.org/iccadocs/E%20CC%20LG%20guidance_FINAL_07-10-2013.pdf.

IEA (2014). CO_2 Emissions from fuel Combustion. International Energy Agency.

IEA ECBCS, 2010. Guidebook on energy efficient lighting for buildings. Aalto University School of Science and Technology.

JCIA, 2011. Life Cycle Analysis of Chemical Products in Japan - carbon-Life Cycle Analysis (c-LCA). Japan Chemical Industry Association.

OSRAM, 2009. Life Cycle Assessment of Illuminants A Comparison of Light Bulbs, Compact Fluorescent Lamps and LED Lamps.

UNEP, 2012. MEPS Scenario Modelling Tool v1.61_beta. United Nations Environment Programme & en.lighten. Available at: http://learning.enlighten-initiative.org/Tools.aspx.

Welz, Hischier and Hilty, 2011. Environmental impacts of lighting technologies — Life cycle assessment and sensitivity analysis. In: *Environmental Impact Assessment Review, 31, p334-343.*

5.5 Transport: Fuel efficient tires

5.5.1 Contribution of chemical industry

Road transport (including cars, busses, and trucks) accounts for more than two thirds of the final energy consumption.[39] Roughly 20% of automobiles' fuel consumption is used to overcome rolling resistance of the tires (IEA, 2005). Fuel efficient tires have lower rolling resistance compared to normal tires, while providing enhanced road-gripping performance, resulting in an energy efficiency improvement of about 2.5% (ICCA/JCIA, 2015). Chemical products such as synthetic rubbers and silica are key components in reducing energy loss and enabling improved fuel efficiency of tires.

5.5.2 Avoided emissions potential calculation

Functional unit

The selected functional unit is driving passenger cars ("cars") (12,318 billion kilometres), plus trucks and buses ("trucks") (4,241 billion kilometres) in the world in 2010. The potential avoided emissions are calculated by the difference in life cycle GHG emissions for motor vehicles with fuel efficient tires and the baseline (currently implemented technologies). Largest part of the difference comes from the energy savings in the use phase. As stated above, the duration of the function is defined to be one year, the time reference is set to 2010 and the chosen geographical region is defined to be the world.

Solutions to compare

Three solutions to compare are identified, including no implementation, current implementation, and maximum implementation of fuel efficient tires. Unfortunately no data is available on global market shares of fuel efficient tires. The market shares for Japan are used as proxy for the global market shares for the current implementation (ICCA/JCIA, 2015).

Table 33. Solutions to compare.

Solutions to compare	Market shares	
	Conventional tires	Fuel efficient tires
No implementation of fuel efficient tires	100%	0%
Current implementation of fuel efficient tires	81%	19%
Maximum implementation of fuel efficient tires	0%	100%

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[39] Final energy consumption for road transport for passengers and freight account for 80 EJ compared a total final energy consumption for transport of 103 EJ in 2012 according to IEA, 2015. Energy Technology Perspectives.

Calculation sequence and key sources

The potential avoided emissions of fuel efficient tires are calculated for driving passenger cars ("cars"), trucks and busses ("trucks") in the world for one year. The potential avoided emissions are calculated by the difference in life cycle GHG emissions for motor vehicles with fuel efficient tires and the baseline (currently implemented technologies) assuming that tire inflation pressure and all other relevant tire performance are maintained at their recommended values.[40]

Global energy consumption for road transport – The fuel consumption of the road transport sector is obtained from the IEA Energy Balance (IEA, 2012). Shares of cars and trucks in the total energy consumption are estimated based on the Global Energy Assessment (IIASA, 2012).

Table 34. Global energy consumption for road transport in 2010. Source: IEA, 2012.

Energy carrier	Energy demand (Mtoe)	Scope*
Oil products	1,733	Included
Natural gas	27	Included
Biofuels	56	Included
Electricity	0.1	Excluded

* Electricity is excluded due to limited impact on results.

Table 35. Share of cars and trucks in global energy consumption for road transport.

Transport mode	Share in energy consumption*
Cars	60%
Trucks	40%

* Assumption based on IIASA (2012) Global Energy Assessment – Toward a Sustainable Future. Chapter 9: Energy End-Use: Transport, Figure 9.21.

Table 36. Kilometres driven by cars and trucks. Source: ICCT (2012).

Transport mode	Distance (billion km)
Light-duty vehicles (LDVs)	12,318
Total cars	**12,318**
Buses	810
LHDT	1,430
MHDT	953
HHDT	1,048
Total trucks	**4,241**

Technological characteristics of conventional tires and fuel efficient tires – Assumptions on the performance of fuel efficient tires and conventional tires are provided in the JCIA case study

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[40] Note that tire construction and maintenance play a critical role in tire performance and fuel economy.

(ICCA/JCIA, 2015). Relevant parameters include the efficiency improvement, service life and the production emissions. The efficiency improvement from the ICCA/JCIA case study is compared with various other sources that show similar improvements.[41]

Table 37. Fuel consumption of cars and trucks with conventional tires and fuel efficient tires based on case of Japan. Source: ICCA/JCIA (2015) Case Study: Materials for Fuel Efficient Tires.

	Conventional tire (L/km)*	Fuel efficient tire (L/km)*	Efficiency improvement
Cars	0.1	0.0975	2.5%
Trucks	0.25	0.2375	5.0%

* The fuel consumption with conventional tire and fuel efficient tire are only used for calculating the efficiency improvement. Average fuel consumption for cars and trucks are calculated from the distance travelled (ICCT, 2012) and the fuel consumption (IEA, 2012).

Table 38. Number of tires and service life for cars and trucks. Source: ICCA/JCIA (2015) Case Study: Materials for Fuel Efficient Tires.

	Number of tires (-)	Service life (km)*
Cars	4	30,000
Trucks	10	120,000

* This service life is assumed for simplicity. Actual service life is dependent on driving conditions, tire composition and inflation pressure.

Table 39. Emission factor (kgCO$_2$e/unit of service life) for conventional and fuel efficient tires. Source: ICCA/JCIA (2015) Case Study: Materials for Fuel Efficient Tires.

Stage	Cars		Trucks	
	Conventional tire	Fuel efficient tire	Conventional tire	Fuel efficient tire
Manufacture	100.0	95.6	1480	1397
Production	31.2	28.0	356	352
Distribution	6.4	6.0	104	101
Disposal and recycling	11.6	2.8	-311	-309

The emissions in the use phase are calculated based on global energy consumption for road transport from the IEA (Table 34), the share of cars and truck in the global energy consumption for road transport (Table 35) and the kilometres driven by cars and trucks (Table 36), resulting in the average fuel consumption (Table 40); as well as the efficiency improvement and the emission factors (Table 3). In this calculation an energy content of 36.4 MJ/L is assumed. The emissions in the manufacturing, production, distribution and disposal and recycling phase are calculated based on the emission factors combined with data on the distance driven. Note that these emissions are slightly lower for fuel efficient

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[41] The JATMA Tire Labeling System shows a Rolling Resistance Coefficient reduction of 14% between a normal tire (label B) and a fuel efficient tire (label A). According to the JATMA LCA report the tire's proportion of the energy consumption is 12.5%, however, this is depending on the drive mode (city drive: 7-10%, JC08 Mode drive: 10-20%, constant velocity drive: 20-25%), resulting in an expected efficiency improvement of 1-5%. Also the JAFMAte test drive report reports efficiency improvements up to 5% in constant velocity drive mode. A 2.5% increase in energy efficiency by fuel efficient tires correspond to average (not the best) fuel efficient tires under the JC08 Mode drive.

tires compared with conventional tires. To estimate the number of tires required in one year, data on distances driven are obtained from the International Council on Clean Transportation Roadmap model (ICCT, 2012).

Table 40. Fuel consumption of cars and trucks on average. Calculated based on the IEA energy balance and the distance driven from ICCT.

	Average tire (L/km)*	Conventional tire
Cars	0.1017	0.1022
Trucks	0.1970	0.1989

Results

Multiple options to reduce fuel consumption in the road transport sector need to be tapped to limit GHG emissions. Using fuel efficient tires on all cars today would result in net annual emission reductions of 228 $MtCO_2e$.

Avoided emissions from fuel efficient tires are dominated by the fuel economy in the use phase, but also the production of fuel efficient tires does have a slightly smaller footprint compared to conventional tires.

Table 41. Annual (avoided) emissions for fuel efficient tires.

Solutions to compare	Emissions ($MtCO_2e$)
No implementation of fuel efficient tires	7,197
Current implementation of fuel efficient tires	7,144
Maximum implementation of fuel efficient tires	6.915
Annual realised avoided emissions – Current implementation level	54
Annual avoided emissions potential – Maximum implementation level	228

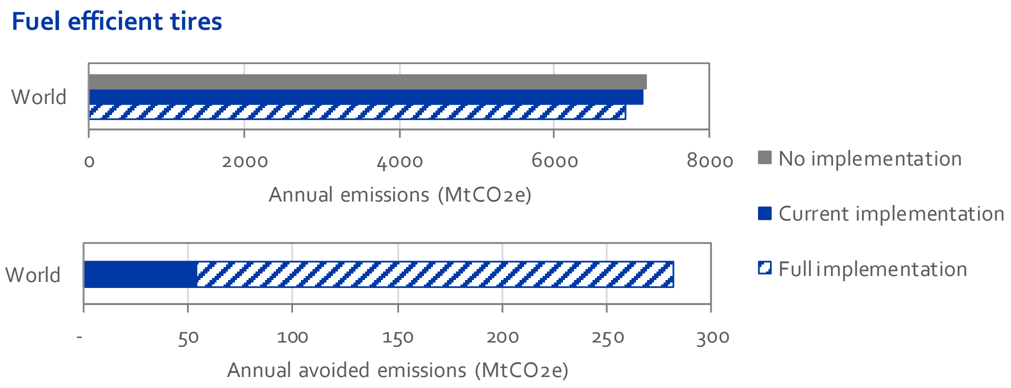

Figure 22. Annual (avoided) emissions for fuel efficient tires. The first graph shows the road transport emissions. The second graph shows the annual realized and potential avoided emissions from the use of fuel efficient tires.

5.5.3 Scenario analysis

The scenario analysis for all transport case studies is combined in Section 5.8.

5.5.4 References

ICCA/JCIA, 2015. Case Study: Materials for Fuel Efficient Tires. Available at: http://www.icca-chem.org/Public/Avoided%20Emissions%20Case%20Studies/Case%20study%201%20-%20Avoided%20Emissions%20Guideline%20-%20JCIA.pdf

ICCT, 2012. International Council on Clean Transportation Roadmap model. Available at: http://www.theicct.org/global-transportation-roadmap-model

IEA, 2005. Energy Efficient Tyres: Improving the On-Road Performance of Motor Vehicles, IEA Workshop, 15-16 November 2005, OECD/IEA, Paris, www.iea.org/work/2005/EnerEffTyre/summary.pdf

IEA, 2012. World Energy Balance 2012.

IEA, 2015. Energy Technology Perspectives.

IIASA, 2012. Global Energy Assessment – Toward a Sustainable Future. Available at: http://www.globalenergyassessment.org/

5.6 Transport: Lightweight materials for cars

5.6.1 Contribution of chemical industry

Lightweight materials reduce the fuel demand of cars. Innovative lightweight materials reduce car weight substantially. Chemical products such as plastics and carbon reinforced plastics are key in achieving strong weight reductions of cars.

5.6.2 Avoided emissions potential calculation

Functional unit

The selected functional unit is driving passenger cars ("cars") in the world in 2010, which is equal to 12,318 billion kilometres travelled by light duty vehicles for passenger transport (ICCT, 2012). The potential avoided emissions are calculated by the difference in life cycle GHG emissions for cars with lightweight materials and the baseline (the current mix of cars with and without lightweight materials). Different materials are used in car manufacturing: steel, aluminium, high strength steel (HSS), plastics, magnesium, carbon fibre and other materials. Within this study the scope is limited to lightweight materials produced by the chemical industry, which are considered to be plastics and carbon fibre reinforced plastics (further abbreviated as carbon fibre).

Solutions to compare

Three solutions to compare are identified, including no implementation, current implementation and maximum implementation of lightweight materials (Table 42 and Figure 23). The material mixes of the current implementation and the maximum implementation are based on the study "Lightweight, heavy impact: How carbon fibre and other lightweight materials will develop across industries and specifically in automotive" by McKinsey (2012). The followed methodology will be explained in detail in the next sections.

Table 42. Three solutions to compare.

Solutions to compare	Description
No implementation of lightweight materials	This represents a hypothetical 2010 situation without lightweight materials being used in car manufacturing.
Current implementation of lightweight materials	This is the present material mix (incl. lightweight materials) in 2010.
Maximum implementation of lightweight materials	This represents a hypothetical situation with a maximum share of lightweight materials in car manufacturing.

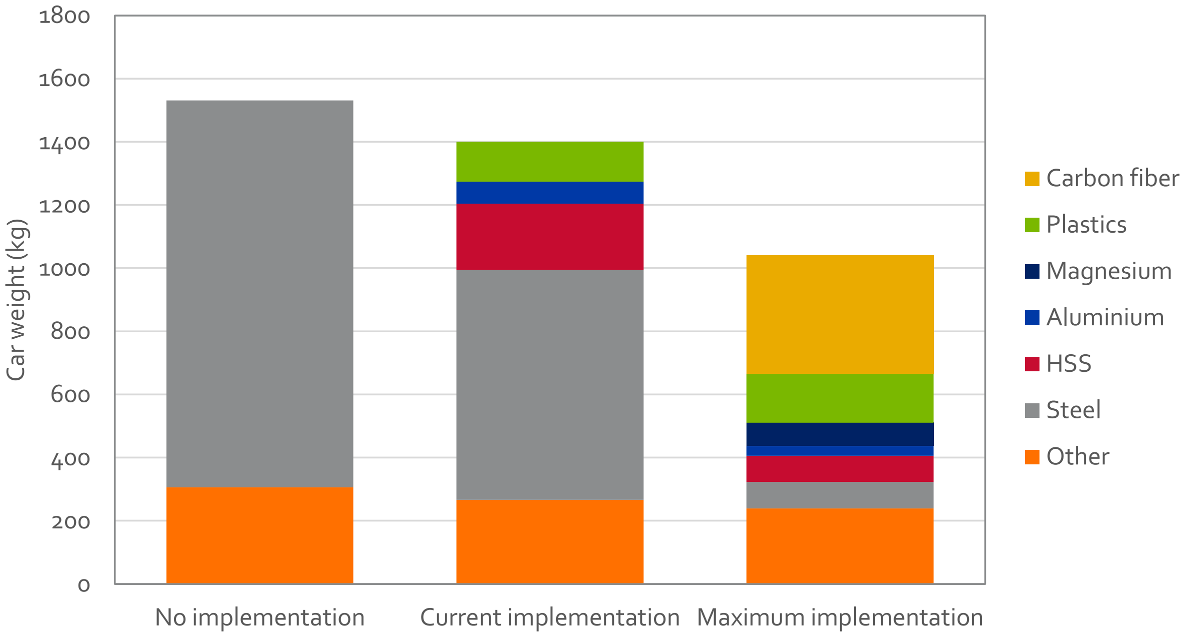

Figure 23. Material mixes per solution to compare. Current and maximum implementation are based on McKinsey, 2012.

Calculation sequence and key data sources

The avoided emissions are calculated by the difference in life cycle GHG emissions associated with driving passenger cars in the world in 2010. Total GHG emissions per solution to compare are calculated as follows:

- Use phase:
  - Calculation weight reduction by the use of plastic and carbon fibre in passenger cars.
    - Calculation of material weight for each solution to compare based data from McKinsey on lightweight packages data for the automotive industry (McKinsey, 2012).
    - Calculation of reduction percentage caused by the replacement of steel by plastic and carbon fibre.
  - Calculation fuel demand (incl. fuel savings due to weight reduction) in the world in 2010.
    - Calculation reference fuel demand based on global vehicle kilometres driven in 2010.
    - Calculation fuel savings due to weight reduction based on a fuel consumption reduction factor.
    - Calculation of worldwide fuel demand by subtracting the fuel savings from the total fuel demand.
  - Calculation use phase emissions by multiplying the global fuel demand by the emission factor of oil products.
- Production

  - Based on the total amount of used plastic and carbon fibre and the reduction in weight, the amount of avoided steel is calculated (i.e. avoided steel use = weight reduction + plastic use + carbon fibre use).
  - Calculation avoided steel production emissions by multiplying the amount of avoided steel use by the emission factor of steel production
  - Calculation emissions during production of plastic and carbon fibre by multiplying the amount of plastic and carbon fibre use by the emission factors of plastic and carbon fibre production.
- The realized and potential avoided emissions are determined by respectively the difference between the solutions to compare "no implementation" and "current implementation", and the difference between the solutions to compare "current implementation" and "maximum implementation".

Input data sources and assumptions

Table 43 indicates the material mixes per solution to compare. The material mix for the current implementation and maximum implementation is based on McKinsey data on lightweight packages for the automotive industry (McKinsey, 2012). The lightweight packages indicate the share of various (lightweight) materials in order to realise a reduction in car weight. Three different lightweight packages are distinguished: conventional, moderate and extreme lightweight. The extreme lightweight package is considered to be the solution "maximum implementation". Besides the lightweight packages, McKinsey (2012) also describes the material split in 2010, which is considered to be the solution "current implementation". The solution "no implementation" represent the mix without any lightweight materials, for which it is assumed that it consist of 80% steel and 20% other materials.

Table 43. Material mixes with weight reduction per solution to compare. Based on McKinsey, 2012.

Description	No implementation	Current implementation	Maximum implementation
Weight reduction compared to no implementation (kg)	0	131	490
Material mix (mass %)			
Steel	80%	52%	8%
HSS	0%	15%	8%
Aluminium	0%	5%	3%
Percentage magnesium	0%	0%	7%
Plastics	0%	9%	15%
Carbon fibre	0%	0%	36%
Other materials	20%	19%	23%

Table 44 indicates the weight advantage of a range of materials against steel. The weight advantage is a combined effect of using lower density materials and using (depending on their properties) lessor more volume of material. For example, the weight of carbon fibre is only half of the weight of steel.

Steel can be replaced by other materials, but the particular material used to replace steel will depend on its characteristics and the application purpose.

Table 44. Material weight advantages against steel. Source: McKinsey, 2012.

Description	Percentage of steel
Aluminium	60%
Plastics	80%
Steel	100%
HSS	80%
Other	100%
Carbon fibre	50%
Magnesium	60%

In Table 45 various car characteristics are provided. The service life of the car represents the average lifetime of the car. The fuel consumption represents the reference fuel consumption of cars. The car weight mainly influences the rolling resistance of cars. The fuel consumption reduction parameter describes the fuel reduction per 100 kg of mass reduction and 100 km driven. In Table 46 the production emission factors for the materials steel, plastic and carbon fibre are shown. The end-of-life phase of these materials is excluded. Especially for carbon fibre reinforce plastics this could provide additional benefit. However, currently no reliable information is available the benefits of recycling.

Table 45. Car characteristics.

Description	Value	Unit	Source
Service life	150,000	km	Case study fuel efficient tires (JCIA, 2014)
Fuel consumption	0.1017	L/km	Estimation based on distance driven from ICCT (2012) and fuel consumption from IEA (2012)
Fuel consumption reduction factor*	0.12	L/100 km/100 kg	Koffler, 2010
Fuel emission factor	3.032	$kgCO_2e/L$	Calculated based on emission factors in section 1.1.

* The fuel consumption reduction factor only includes the direct effect. Avoided emissions including consequential effects, such as fuel consumption reduction due to engine down-sizing can be significantly larger.

Table 46. Material production emission factors.

Description	Value	Unit	Source
Steel	4.6	$kgCO_2e$/kg steel	Ecoinvent 3 process Steel, chromium steel 18/8 {GLO}| market for | Alloc Rec, U
Plastics	3.7	$kgCO_2e$/kg plastic	Ecoinvent 3 process Polystyrene, high impact {GLO}| market for | Alloc Rec, U)

Carbon fibre	9.3	$kgCO_2e/kg$ carbon fibre	Based on Zhang et al., 2011 it is assumed that the carbon fibre material consists of 30% carbon fibre (22.4 $kgCO_2e/kg$) and 70% plastics (3.7 $kgCO_2e/kg$).

Calculated parameters

On the basis of the car weight and the shares of materials in Table 43, the material weight of steel, high strength steel (HSS), aluminium, magnesium, plastics, carbon fibre and other materials is calculated (Table 47). Since the focus of this study is on the weight reduction by plastics and carbon fibre only, the share of these materials in the total weight reduction need to be calculated. Ideally, this should be calculated from the plastic and carbon fibre used and the weight advantages of these materials against steel (i.e. 80% for plastic and 50% for carbon fibre) (Table 44). Example: If steel parts can be replaced by plastics, this will in general result in a weight reduction from 100% to 80%, i.e. 20%. This means 128 kg of steel is replaced by 103 kg of plastic (103 kg plastic * (1 / 80%)). Unfortunately, this bottom-up calculation results in an overestimation of the total weight reduction of the car. Therefore, all lightweight material weights are converted to material weights in steel equivalents (Table 48). The weight reduction reported by McKinsey is then allocated to the various materials based on their share in the steel equivalents (Table 49).

Table 47. Material weights (kg).

Description	No implementation	Current implementation	Maximum implementation
Total weight car	**1531**	**1400**	**1041**
Steel	1225	728	83
HSS	0	210	83
Aluminium	0	70	31
Magnesium	0	0	73
Plastics	0	126	156
Carbon fibre	0	0	375
Other	306	266	239

Table 48. Weights of lightweight materials in steel equivalents (kg steel equivalents).

Description	No implementation	Current implementation	Maximum implementation
HSS	0	263	104
Aluminium	0	117	52
Magnesium	0	0	121
Plastics	0	158	195
Carbon fibre	0	0	749

Table 49. Shares of lightweight materials based on material weights in steel equivalents (%).

Description	No implementation	Current implementation	Maximum implementation
HSS	-	49%	9%
Aluminium	-	22%	4%
Magnesium	-	0%	10%
Plastics	-	29%	16%
Carbon fibre	-	0%	61%

The percentage of plastic and carbon fibre multiplied by the difference in car weight between the solutions to compare gives the reduction in kilograms, which can be attributed to plastic and carbon fibre (Table 50). Total GHG emissions are calculated by the total fuel demand in 2010 multiplied by the emission factor for oil products. Fuel demand in 2010 is calculated by the global vehicle kilometres driven in 2010 multiplied by a fuel consumption of 0.1017 L/km, which is calculated from the IEA Energy Balance (IEA, 2012) and the kilometres driven from the ICCT model (ICCT, 2012). In this calculation an energy content of 36.4 MJ/L is assumed. The fuel savings due to weight reduction are subsequently subtracted from this number. Fuel savings due to weight reduction are calculated by multiplying the weight reduction in kilograms by a fuel consumption reduction factor of 0.12 L/100km/100 kg (Table 45) (Koffler, 2010.).[42]

Table 50. Weight reduction by plastic and carbon fibre.

Description	No implementation	Current implementation	Maximum implementation
Weight reduction by plastics (kg)	0	38	78
Weight reduction by carbon fibre (kg)	0	0	300

Table 51. Emission reduction by plastic and carbon fibre.

Description	No implementation	Current implementation	Maximum implementation
Global vehicle kilometres driven in 2010 (billion km)	12,318		
Fuel demand (billion L)	1,258	1,253	1,202
Emissions ($MtCO_2e$)	3,815	3,798	3,646

Table 52 indicates the emissions from plastic and carbon fibre production. Additionally Table 52 indicates the prevented emissions due to avoided steel production. Emissions from plastic and carbon fibre production are first calculated per car, based on the amount of plastic and carbon fibre and production emission factors. Secondly, the calculated emissions are multiplied by the number of passenger cars in 2010, which are calculated based on the global vehicle kilometres driven in 2010 divided by a car life time of 150,000 km. Avoided emissions steel production are calculated in the same

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[42] The range in the fuel consumption reduction factor reported across various studies is quite high. Ranges are reported from 0.10 to 0.35 L/100 km/100 kg.

way. The amount of avoided steel is equal to the sum of the amount of plastic production, carbon production and weight reduction.

Table 52. Emissions due to plastic and carbon fibre production and avoided steel production emissions.

Description	No implementation	Current implementation	Maximum implementation
Production (kg)			
Avoided steel	0	164	909
Plastic	0	126	156
Carbon fibre	0	0	375
Emissions per car (kgCO_2e)			
Avoided emissions steel production	0	748	4,140
Emissions plastic production)	0	462	573
Emissions carbon fibre production	0	0	3,484
Total emissions (MtCO_2e)			
Avoided emissions steel production globally	0	61	340
Emission plastic production	0	38	47
Emissions carbon fibre production	0	0	286

Results

Multiple options to reduce fuel consumption in the road transport sector need to be tapped to limit GHG emissions. Using high shares of plastics (15%) and carbon fibres (36%) in all cars today would result in annual emission reductions of 136 MtCO_2e.

As result of choosing a conservative value for the fuel reduction factor, avoided emissions in the use phase and emissions in the production phase are in the same order of magnitude. The end result is therefore highly sensitive toward the production emission factors of steel, plastics and carbon fibre. Higher emission factors for plastics and carbon fibre or lower emission factors for steel will result in diminishing benefits. Avoided emissions are also sensitive to fuel savings per 100 kg per 100 km.

Table 53. Annual (avoided) emissions for lightweight materials.

Solutions to compare	Emissions (MtCO2e)				
	Use	Production – avoided steel emissions	Production - plastics	Production – carbon fibre	Total
No implementation	3,815	0	0	0	3,815
Current implementation	3,798	61	38	0	3,775
Maximum implementation	3,646	340	47	286	3,639
Annual realised avoided emissions – Current implementation level	-	-	-	-	41
Annual avoided emissions potential – Maximum implementation level	-	-	-	-	136

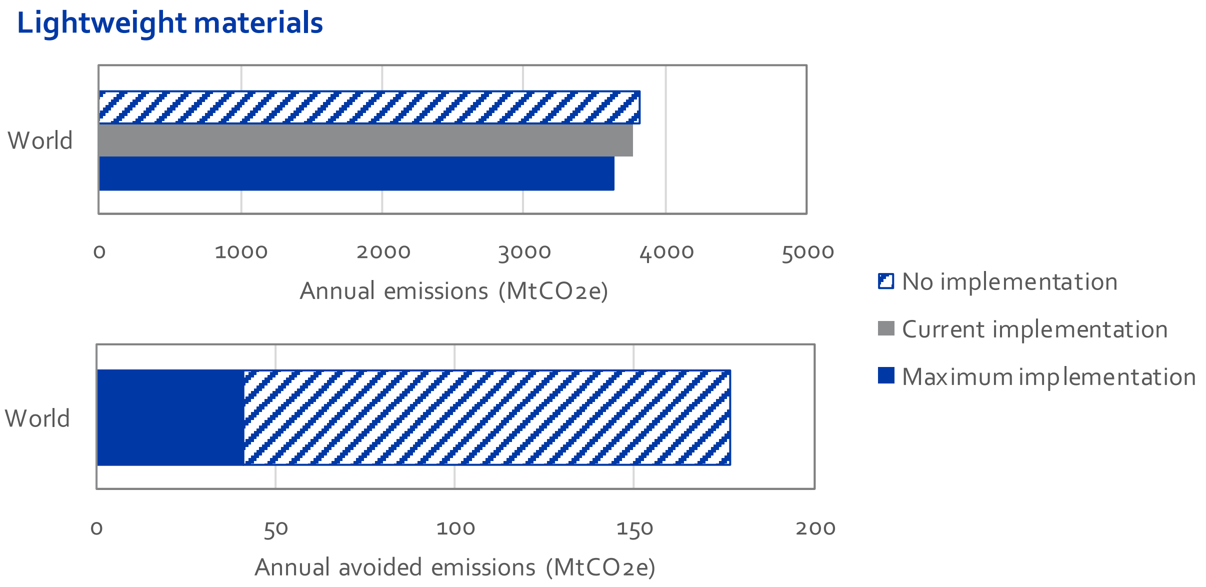


Figure 24. Annual (avoided) emissions for lightweight materials. First graph shows the annual emissions related to driving passenger cars, the second graph shows the annual realized and potential avoided emissions.

5.6.3 Scenario analysis

The scenario analysis for all transport case studies is combined in Section 5.8.

5.6.4 References

ICCA/JCIA, 2015. Case Study: Materials for Fuel Efficient Tires. Available at: http://www.icca-chem.org/Public/Avoided%20Emissions%20Case%20Studies/Case%20study%201%20-%20Avoided%20Emissions%20Guideline%20-%20JCIA.pdf

ICCA/Solvay, 2015. Case study: Vehicle light-weighting: an example of metal replacement by engineering plastics. Not published yet.

ICCT, 2012. International Council on Clean Transportation Roadmap model. Available at: http://www.theicct.org/global-transportation-roadmap-model

IEA, 2012. World Energy Balance 2012.

IEA, 2015. Energy Technology Perspectives.

IFEU, 2003. Energy savings by light-weighting. Available at: https://www.alcoa.com/global/en/environment/pdf/IFEU(2003)_Energy_savings_by_light_weighting_-_I.pdf

Koffler, C., Rohde-Brandenburger, K., 2010. On the calculation of fuel savings through lightweight design in automotive life cycle assessment. In: Environmental science & technology, 47, p12632-12647.

McKinsey, 2012. Lightweight, heavy impact: How carbon fibre and other lightweight materials will develop across industries and specifically in automotive.

Zhang, X., M. Yamauchi, and J. Takahashi, 2011. "Life Cycle Assessment of CFRP in Application of Automobile." 18th International Conference on Composite Material. Available at: http://www.iccm-central.org/Proceedings/ICCM18proceedings/data/2.%20Oral%20Presentation/Aug25(Thursday)/Th44%20High%20Performance%20and%20Sustainable%20Composite%20Materials/Th44-3-AF1668.pdf

5.7 Transport: Electric cars

5.7.1 Contribution of chemical industry

Multiple options to reduce fuel consumption in the road transport sector need to be tapped to limit global warming. Emission reductions can be enabled by transport demand reductions, but also by efficient technologies, such as fuel efficient tires, lightweight materials and electric cars. Electrification of road transport enables deep decarbonisation of the energy demand, because renewable electricity can be supplied on a large scale. Furthermore, electric cars have a higher energy efficiency compared to cars with conventional combustion engines. Chemical products play a key role in the production of batteries required for electric cars. These include anode materials , cathode materials, electrolyte and separators.

5.7.2 Avoided emissions potential calculation

Functional unit

The selected functional unit is driving passenger cars in the world in 2010, which is equal to 12,318 billion kilometres by light duty vehicles for passenger transport (ICCT, 2012). The potential avoided emissions are calculated by the difference in life cycle GHG emissions for full electric vehicles and the baseline (the current mix of electric and non-electric vehicles).

Solutions to compare

Three solutions to compare are identified, including no implementation, current implementation and maximum implementation of electric vehicles (Table 54). The study calculates the already realized avoided emissions by comparing the current mix of electric and non-electric vehicles (i.e. current implementation) with the reference situation of no electric vehicles (i.e. no implementation). The maximum potential for avoided emissions is calculated by comparing a hypothetical situation with a maximum share of electric vehicles (i.e. maximum implementation) with the current implementation of electric vehicles in the market. In reality the maximum share of electric vehicles will depend on a range of factors of which amongst others the availability of rare earth metals.

Table 54. Three solutions to compare.

Solutions to compare	Market shares Non-electric vehicles	Electric vehicles
No implementation of electric vehicles	100%	0%
Current implementation of electric vehicles*	99.99%	0.01%
Maximum implementation of electric vehicles	0%	100%

* Based on the reported electricity consumption of road transport in the IEA Energy Balance (IEA, 2012).

Calculation sequence and key data sources

The avoided emissions are calculated by the difference in the life cycle GHG emissions associated with driving light duty vehicles for passenger transport in the world in 2010. Total life cycle GHG emissions per solution to compare are calculated based on the direct and indirect emissions as follows:

- Production and end-of-life phase (indirect emissions):
    - The average number of vehicles needed annually to provide the driving is determined by dividing the total distance driven by the service life (i.e. number of kilometres) of one passenger car.
    - The emissions are calculated by multiplying the number of non-electric and electric vehicles with the emissions factors for production and end-of-life phases, which are adopted from a Renault LCA study (Renault, 2011).
- Use phase (direct emissions):
    - Fuel demand of non-electric vehicles is calculated based on global fuel consumption of road transport obtained from the IEA Energy Balance (IEA, 2012), the estimated share of cars and trucks in the total energy consumption based on the Global Energy Assessment (IIASA, 2012) and the global vehicle kilometres driven by cars obtained from the ICCT model (ICCT, 2012).
    - Fuel demand of electric vehicles is calculated by multiplying the calculated fuel demand of non-electric vehicles by the ratio between electric/non-electric vehicle fuel consumption, which is derived from a Renault LCA study (Renault, 2011).
    - The emission factor of one litre fuel for a non-electric vehicle is equal to the life cycle emission factor of gas/diesel/fuel oil as given in Table 3.
    - The emission factor of one kWh for an electric vehicle is equal to the life cycle emission factor of electricity generation in the world as given in Table 3.
    - The use phase emissions are calculated by multiplying the fuel demand per vehicle type with the related emissions factor for either one litre fuel or kWh.
- The realized and potential avoided emissions are determined respectively by the difference between the solutions to compare "no implementation" and "current implementation", and the difference between the solutions to compare "current implementation" and "maximum implementation".

Input data sources and assumptions

Table 55 and Table 56 give insight in the total energy consumption of cars in the world. Based on a total distance driven of 12,317 billion kilometres for light duty vehicles in 2010 (ICCT, 2012), a fuel consumption per kilometre can be calculated.

Table 55. Global energy consumption for road transport in 2010. Source: IEA, 2012.

Energy carrier	Energy demand (Mtoe)
Oil products	1,733
Natural gas	27
Biofuels	56

Table 56. Share of cars and trucks in global energy consumption for road transport.

Transport mode	Share in energy consumption*	Scope
Cars	60%	Included
Trucks	40%	Excluded

* Assumption based on IIASA (2012) Global Energy Assessment – Toward a Sustainable Future. Chapter 9: Energy End-Use: Transport, Figure 9.21.

A series of studies compare the life cycle environmental impacts of an electric and a conventional vehicle (Renault, 2012; Audi, 2011; ESU-services, 2010; Aguirre et al., 2012). One of the few studies that compares a diesel/petrol and electric version of one single car is the Renault Fluence LCA study (2011). The fuel consumption of an electric vehicle is calculated based on the non-electric/electric fuel consumption ratio as given in the Renault LCA study (Table 57). The ratio describes the electricity consumption of the electric car compared to the fuel consumption of the conventional car (kWh/L) and is commonly used in comparative LCAs for electric cars. The ratio from the Renault LCA study is relatively conservative when compared to the other LCA studies (i.e. ESU-services, 2010: 3.5; Audi, 2011: 2.7). This means that using the Renault study for calculating the avoided emissions potential of electric cars will not lead to an overestimation of the avoided emissions potential.

Table 57. Fuel consumption non-electric and electric vehicle as reported by Renault Source: Renault, 2011.

Vehicle type	Fuel consumption
Non-Electric (l/km)	0.06
Electric (kWh/km)	0.14
Ratio (kWh/L)	2.33

The use phase emission factor of non-electric vehicles is equal to the life cycle emission factor of gas/diesel/fuel oil. The use phase emission factor of electric vehicles is equal to the current life cycle emission factor of the global electricity mix (0.634 $MtCO_2e/TWh$). Note that the avoided emission potential of electric vehicles heavily depends on developments in the electricity market (i.e. the rate at which the share of renewables is increasing).

The emission factors related to the production (incl. battery) and end-of-life of a non-electric and electric vehicle are derived from the Renault LCA study (Renault, 2011) (Table 58). For each car model type (e.g. diesel, petrol, electric) the production and end-of-life emission factor is calculated based on the total life cycle emission factor and the contribution of non-use phases. Compared to other LCA studies, the Renault LCA study indicates a relatively high contribution of GHG emissions from non-use phases for electric vehicles. This will prevent underestimation of the emissions during for example battery production. Worth mentioning is the fact that the total emissions of an electric vehicle will partly be determined by the electricity mix (e.g. 100% renewable or the average mix). Within the Renault LCA study, an average EU electricity mix is taken.

Table 58. Emission factor for electric and non-electric vehicles.

	Non-electric vehicle		Electric vehicle	Source
	Diesel	Petrol		
Life cycle emission factor (kg CO_2e/vehicle)	25,547	34,951	15,580	Renault, 2011
Contribution all phases, excluding use and well-to-tank	23.7%	18.5%	58.9%	Renault, 2011
Production and end-of-life life cycle emission factor (kgCO_2e/vehicle)	6,055	6,466	9,177	Calculated

Calculated parameters

The fuel consumption data in Table 57 is specific for the Renault Fluence. In Table 59 the fuel consumption calculated from the IEA Energy Balance (IEA, 2012) and the kilometres driven (12,318 billion kilometres) from the ICCT model (ICCT, 2012) is showed. In this calculation an energy content of 36.4 MJ/L is assumed. The fuel efficiency for electric vehicles is calculated based on the ratio calculated in Table 57.

Table 59. Calculated fuel consumption non-electric and electric vehicles.

Vehicle type	Fuel consumption
Non-Electric (l/km)	0.1017
Electric (kWh/km)	0.2370

Table 60 shows the distance driven, fuel demand and related emissions in 2010 per solution to compare. Table 61 shows the number of non-electric and electric vehicles produced in the year 2010 and related emissions during production and end-of-life.

Table 60. Use phase emissions per solution to compare per year.

	Non-electric vehicle	Electric vehicle
No implementation		
Distance driven (billion km)	12,318	0
Fuel demand (billion L fuel or billion kWh)	1,253	0
Emissions (MtCO_2e)	3,799	0
Current implementation		

	Non-electric vehicle	Electric vehicle
Distance driven (billion km)	12,317	1.2
Fuel demand (billion L fuel or billion kWh)	1,253	0.3
Emissions (MtCO$_2$e)	3,789	0.2
Maximum implementation		
Distance driven (billion km)	0	12,318
Fuel demand (billion L fuel or billion kWh)	0	2,919
Emissions (MtCO$_2$e)	0	1,851

Table 61. Production and end-of-life phase emissions per solution to compare.

	Non-electric vehicle	Electric vehicle
Emission factor (kgCO$_2$/vehicle)	6,355	9,177
No implementation		
Number of vehicles* (million)	82	0
Emissions (MtCO$_2$e)	522	0
Current implementation		
Number of vehicles* (million)	82	0
Emissions (MtCO$_2$e)	522	0
Maximum implementation		
Number of million vehicles*	0	82
Emissions (MtCO$_2$e)	0	754

* Calculated based upon the global vehicle kilometres driven in 2010 (i.e. 12,318 billion km) divided by the vehicle service life (150,000 km) and multiplied by the percentage of non-electric and electric vehicles per solution to compare.

Results

Global emissions related to driving electric and non-electric passenger vehicles were 4.3 GtCO$_2$e in 2010. If the total vehicle stock would be replaced by electric vehicles emissions this would be 1.7 GtCO$_2$e lower.

Table 62. Annual (avoided) emissions for driving electric vehicles.

Solutions to compare	Global emissions (MtCO$_2$e)
No implementation	4,321
Current implementation	4,320
Maximum implementation	2,604
Annual realised avoided emissions – Current implementation level	<1
Annual avoided emissions potential – Maximum implementation level	1,716

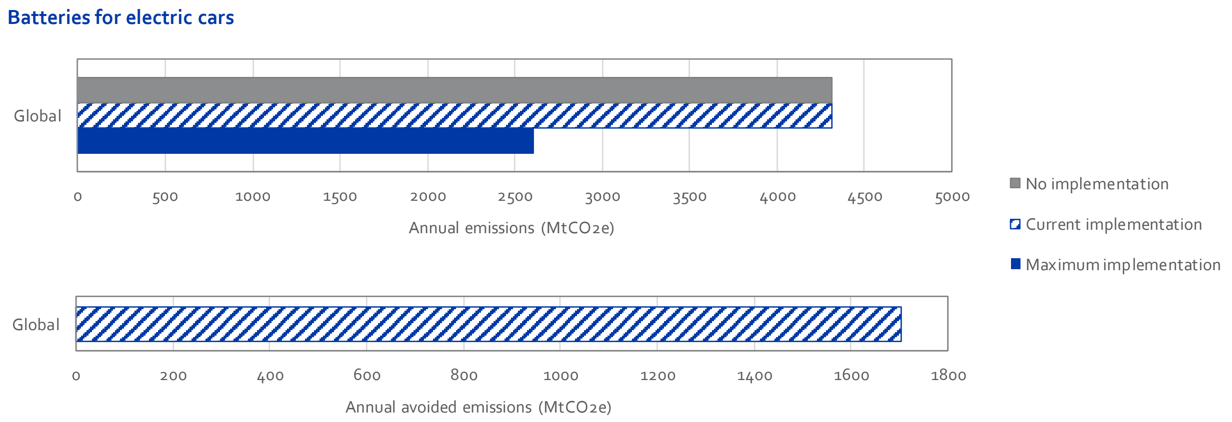


Figure 25. Annual (avoided) emissions for electric cars. First graph shows the annual emissions related to driving, the second graph shows the annual realized and potential avoided emissions.

5.7.3 Scenario analysis

The scenario analysis for all transport case studies is combined in Section 5.8.

5.7.4 References

Aguirre, K., Eisenhardt, L., Lim, C., Nelson., B., Norring, A., Slowik, P. and Tu, N., 2012. Lifecycle Analysis Comparison of a Battery Electric Vehicle and a Conventional Gasoline Vehicle. Available at: http://www.environment.ucla.edu/media/files/BatteryElectricVehicleLCA2012-rh-ptd.pdf

Audi, 2011. Life Cycle Assessment, Audi looks a step ahead. Available at: http://www.audi.com/content/dam/com/EN/corporate-responsibility/product/audi_a6_life_cycle_assessment.pdf

ESU-Services, 2010. Life Cycle Assessment of Battery Electric Vehicles and Concept Cars. Available at: http://www.esu-services.ch/fileadmin/download/leuenberger-2010-BatteryElectricVehicles.pdf

ICCT, 2012. International Council on Clean Transportation Roadmap model. Available at: http://www.theicct.org/global-transportation-roadmap-model

IEA, 2012. World Energy Balance 2012.

IEA, 2015. Energy Technology Perspectives.

IIASA, 2012. Global Energy Assessment – Toward a Sustainable Future. Available at: http://www.globalenergyassessment.org/

Renault, 2011. Fluence and Fluence ZE: Life Cycle Assessment. Available at: https://group.renault.com/wp-content/uploads/2014/09/fluence-acv-2011.pdf

5.8 Transport: Scenario analysis

In the scenario analysis the contributions of fuel efficient tires, lightweight materials and electric cars in reaching the mitigation scenario are investigated. These are combined in one scenario analysis because they impact the contribution of each other. In the following sections we discuss the scenario parameters, differences between the potential avoided emissions calculation and the scenario analysis, as well as the results of the scenario analysis.

Parameters

Emissions for personal road transport can be obtained directly from the ETP 2015 transport tables. This gives a generic view on the development of the emissions in the reference and mitigation scenario in 2030. Further analyses are performed to provide more insights in the role of various measures in transport. The transport emissions calculation is therefore split in several steps: *transport emissions = transport emissions regular + transport emissions electric = distance driven regular * efficiency regular * emission factor regular + distance driven electric * efficiency electric * emission factor electric.* In Table 64 we provide additional explanation on the parameters used in this equation.

To calculate the difference between the reference scenario and the mitigation scenario (blue bars), all relevant parameters from the calculation above are updated according to the scenario quantification (Table 65). The breakdown of the various factors (grey bars) is calculated using a decomposition analysis. In the decomposition analysis only one parameter is changed to investigate the impact of that single parameter. The results of the individual steps in the decomposition analysis are subsequently normalized in proportion to their relative non-normalized contribution to yield the overall emission reduction. The decomposition formula is provided in Section 5.10.4.

Table 63. Explanation of transport emissions equation.

Parameter	Source
Distance driven regular	Demand for transport * (1 – market share of electric cars)
Efficiency regular	Efficiency of transport in 2012 * (1 – efficiency improvement through fuel efficient tires) * (1 – efficiency improvement through lightweight materials) * (1 – other efficiency improvement)
Emission factor regular	(Total emissions – Emissions from electricity) / (Distance driven regular * Efficiency regular)
Distance driven electric	Demand for transport * market share of electric cars
Efficiency electric	Efficiency of transport in 2012 * (1 – efficiency improvement through fuel efficient tires) * (1 – efficiency improvement through lightweight materials) * (1 – efficiency improvement through electrification) * (1 – other efficiency improvement)
Emission factor electric	Determined in the wind and solar power case study
Efficiency of transport in 2015	Calculated based on Energy demand for transport / Demand for transport in 2015, which are obtained from the ETP 2015 transport tables
Efficiency improvement through fuel efficient tires	Calculated based on Market share of fuel efficient tires and an 2.5% efficiency improvement when fuel efficient tires are used.
Efficiency improvement through lightweight materials	Calculated based on the car weight reduction and an efficiency improvement of 0.12 L/100 km/100 kg.

Parameter	Source
Efficiency improvement through electrification	Calculated based on Market share of electric cars and a 72% efficiency improvement when electric cars are used.
Other efficiency improvement	The total efficiency improvement is calculated using energy demand for transport / demand for transport. Efficiency improvement as a result of the identified measures are subsequently excluded to calculate the other efficiency improvement. The ETP 2015 data base year is used as starting point, which is 2.21 PJ/billion km in 2012. Hence there is already some other efficiency improvement in 2015.

Table 64. Source and calculation methodology for scenario parameters for the transport case studies.

Scenario parameter	Source
Demand for transport	Calculated based on the demand for transport in pkm from the ETP 2015 transport tables and a pkm to vkm conversion factor of 0.637 vkm/pkm which is calculated based on ICCT data (12318 vkm / 19340 pkm).
Energy demand for transport	Obtained directly from the ETP 2015 transport tables
Emissions from transport	Obtained directly from the ETP 2015 buildings tables
Market share of fuel efficient tires	Since tires will have relatively short lifetime (<5 year), the market share can increase quickly. In reference scenario we assume there will be a slight increase to 30% market share; in the mitigation we assume a substantial increase to 75% market share. The huge increase of market share is in line with the JCIA case study where a market share of 86% is expected in 2020. Our assumptions for the world are a bit less ambitious, because it also includes less developed countries.
Average weight of a passenger car	Since car have a relatively long lifetime (up to 20 year), market penetration of lightweight materials will be slow. Furthermore, historically we see that car weights hardly drop, even when more and more lightweight materials are used. For the reference scenario we do not assume any weight reductions, for the mitigation scenario we assume the average car weight will decrease from 1400 to 1200 kg by 2030. This expert assumption is based on studies mentioned in Section 5.6.
Market share of electric cars	Obtained from direct communication with IEA.
Emission factor for electricity	Determined in the wind and solar power case study

Table 65. Quantification of scenario parameters for the transport case studies.

Parameter	Unit	2015	2030	
		Reference	Reference	Mitigation
Demand for transport	billion km	22,073	29,994	27,408
Energy demand for transport	PJ	46,996	56,793	36,639
Emissions from transport	$MtCO_2$	4,604	5,544	3,379
Market share of fuel efficient tires	%	20.0	30.0	75.0
Average weight of a passenger car	kg	1400	1400	1200
Market share of electric cars	%	0.1	0.8	15.7
Emission factor for electricity	$MtCO_2$/TWh	0.66	0.59	0.33

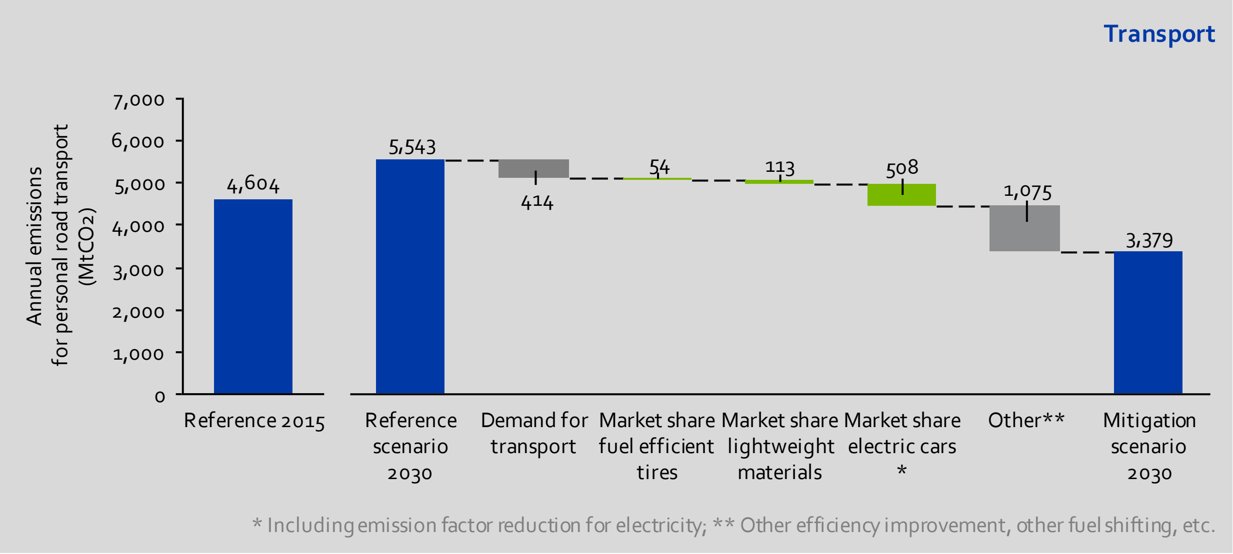
Table 66. Additional information on parameter for the transport case studies.

Parameter	Unit	2015	2030	
		Reference	Reference	Mitigation
Overall efficiency development	PJ/billion km	2.1	1.9	1.3
Overall efficiency improvement	%	4.1	14.7	39.8
Efficiency improvement fuel efficient tires	%	0.5	0.8	1.9
Efficiency improvement lightweight materials	%	0.0	0.0	2.4
Efficiency improvement electric cars	%	0.1	0.6	11.3
Efficiency improvement other	%	3.5	13.5	29.1

Discussion of major differences between avoided emissions potential calculation and scenario analysis

- We combined the several transport case study in one single scenario analysis.
- Emission related to the production of fuel efficient tires, lightweight materials and electric cars are not included in the scenario analysis. This results in limited consequences for fuel efficient tires (< 5%), but potentially large consequences for lightweight materials and electric cars.
- Future recycling development for batteries for electric cars and lightweight materials such as carbon reinforced plastics are uncertain and can significantly affect the GHG benefits of these products.

Results



* Including emission factor reduction for electricity; ** Other efficiency improvement, other fuel shifting, etc.

Figure 26 shows the development of emissions for transport in the reference scenario and the mitigation scenario. Emission reductions are enabled by demand reductions, fuel efficient tires, lightweight materials, electrification as well as many other efficiency improvement measures. In the mitigation scenario, additional fuel efficient tires contribute to over 50 $MtCO_2e$, additional lightweight materials contribute to over 100 $MtCO_2e$ and additional electric cars contribute to over 500 $MtCO_2e$. Transport demand reductions and other efficiency improvements are key to further reduce the emissions from transport.

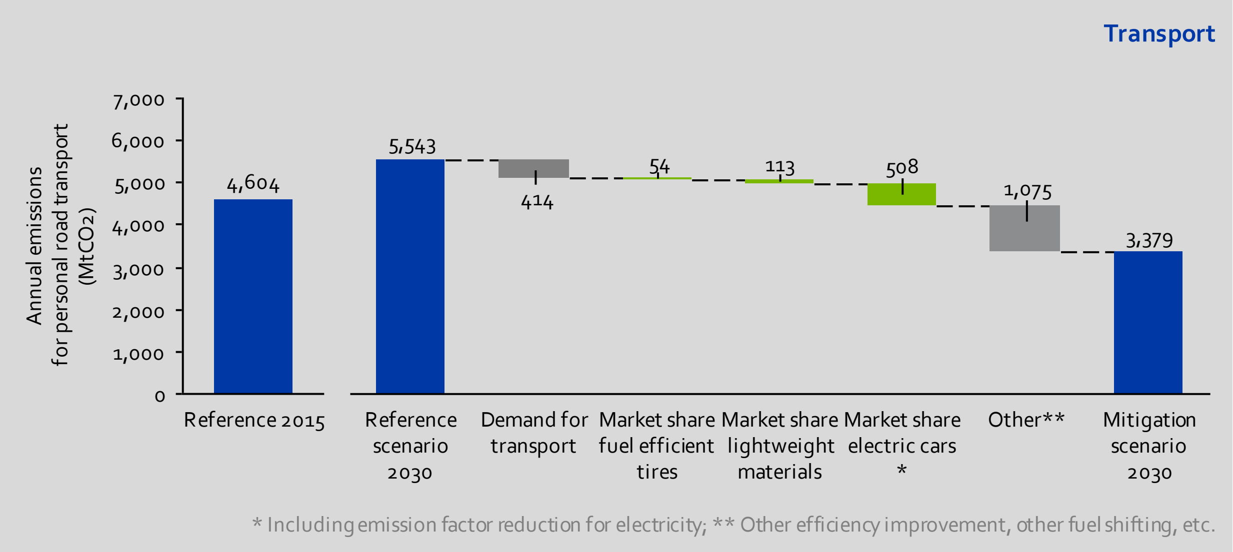


Figure 26. Avoided emissions from fuel efficient tires, lightweight materials and electric cars in the mitigation scenario in 2030.

5.9 Packaging

5.9.1 Introduction

The production of food results in substantial GHG emissions. According to Denkstatt (2014) about 30% of the carbon footprint of an average European can be linked to the production and distribution of food and nutrition. Especially the production of meat has high carbon intensity, up to 20 $kgCO_2e/kg$ for bovine meat (FAO, 2013). At the same time, roughly one-third of the edible parts of food produced for human consumption, gets lost of wasted globally, which amounts to 1.3 billion ton per year (FAO, 2011). Food is lost in the chain from production to retailer as well as at the consumers' home. FOA estimates that the emissions from food produced and not eaten are about 3.3 $GtCO_2e$, excluding impacts from land use change (FAO, 2013). Reducing food loss is therefore key in reducing the carbon impact related to food production.

Packaging can prevent food waste by preventing food spoilage, increasing food quality and safety, increasing shelf-life and providing portions that are suitable for the consumer's needs (Denkstatt, 2014). Denkstatt investigated the changes of food waste shares due to changes in packaging. They show, for example, that better packaging for steak can increase the shelf life from 6 days to 16 days, resulting in a food loss reduction from 34% to 18%. In the study "The impact of plastic packaging on the life cycle energy consumption and greenhouse gas emissions in Europe", it is shown that the GHG benefit of food losses is (on average) at least five time higher than the burden of packaging production, if only 10% less packed food is wasted. The GHG emissions benefits from prevented food losses are estimated at up to 200 $MtCO_2e$/year in Europe (Denkstatt, 2011).

The chemical industry plays a fundamental role in the development and production of these (usually plastics) packaging materials. Both packing goods that are currently not packed and improving the packaging of product that are already packed, can substantially decrease food losses. The avoided emissions in the food production chain are usually substantially higher than the emission impact of the packaging besides the benefits of reducing food losses.

Because the quantitative data on food loss reduction through packaging are limited, we consider it not feasible to perform the potential avoided emissions calculation and scenario analysis as we did for the other case studies. We provide an example calculation for bovine meat below to illustrate how such analysis could look like.

5.9.2 Example

Table 67. Assumptions on analysis parameters for the packaging case study.

Parameter	Value	Source
Market volume of beef (kg)	$64 \cdot 10^9$	FAO statistics
Amount of packaging material used for beef (kg/kg beef)	0.0092	Personal communication with Yuki Kabe on MAP packaging, which weights 9,2 g per kg of fresh meat.
Food losses of beef in distribution and consumption phase	11.8%	Calculation based on meat production, meat wastage and the share of wastage in distribution and consumption from FAO.
Food losses reduction factor plastic packaging	15.0%	Estimation based on GUA, 2005. "Potential effects in the use phase of packaging in general are saved food losses due to the use of packaging (compared to distribution of goods without packaging). In this study it is assumed that 70 % of all food packaging (plastics and other materials) prevent the loss of 20 % of the food packed." and "In addition to the effect described above for all packaging materials, it is assumed in this study that 20 % of the total food packaging made of plastics lead to an extra 5 % saving of food losses compared to a hypothetical scenario, where all plastic food packaging has been substituted by other materials.
Emission factor beef production ($kgCO_2e$/kg)	20	Conservative assumptions based on FAO, 2013. Study reports range of 20 - 30 $kgCO_2$/kg bovine meat.
Emission factor plastics ($kgCO_2e$/kg)	2.6	Estimation based on Ecoinvent data 3 for the production and EOL of polyethylene.[43]

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[43] I.e. Ecoinvent 3 entries Polyethylene, low density, granulate {GLO}| market for | Alloc Rec, S and Waste polyethylene/polypropylene product {GLO}| market for | Alloc Rec, U

Table 68. Potential avoided emissions calculation for the packaging case study.

Parameter	No implementation	Current implementation	Full implementation	Source
Market volume of beef (kg)	$64.6 \cdot 10^9$	$64.0 \cdot 10^9$	$63.4 \cdot 10^9$	Calculated
Food waste	$8.1 \cdot 10^9$	$7.6 \cdot 10^9$	$7.0 \cdot 10^9$	Calculated
Market share of (plastic) packaging[a]	0%	50%	100%	Estimation based on GUA, 2005. "Approximately 50 % of goods is packed in plastic packaging; for food, the same share is assumed."
Emissions beef production ($MtCO_2$)	1,291	1,280	1,269	Calculated
Emissions beef production food waste ($MtCO_2$)	162	151	140	Calculated
Market volume of plastics (kg)	0	$0.3 \cdot 10^9$	$0.6 \cdot 10^9$	Calculated
Emissions plastics ($MtCO_2$)	0	0.8	1.5	Calculated
Avoided emissions ($MtCO_2$)	0	10.6	10.6	Calculated

[a] No other packaging materials are considered.

5.9.3 References

Denkstatt, 2011. The impact of plastic packaging on the life cycle energy consumption and greenhouse gas emissions in Europe. Executive summary available at: http://www.plasticseurope.org/documents/document/20111107113205-e_ghg_packaging_denkstatt_vers_1_1.pdf

Denkstatt, 2014. How Packaging Contributes to Food Waste Prevention. Available at: http://denkstatt.at/files/How_Packaging_Contributes_to_Food_Waste_Prevention_V1.2.pdf

FAO, 2013. Food Wastage Footprint: Impact on natural resources. Technical Report. Available at: http://www.fao.org/ docrep/018/ar429e/ar429e.pdf

FAO, 2011. Global Food Losses and Food Waste: Extent, causes and prevention. Chapter 3: The extend of food losses and waste. Available at: http://www.fao.org/docrep/014/mb060e/mb060e.pdf

GUA, 2005. The Contribution of Plastic Products to Resource Efficiency. Available at: http://www.plasticseurope.org/cust/documentrequest.aspx?DocID=661

5.10 Decomposition analysis

5.10.1 Wind and solar power

GHG emission by power generation is defined by a function G,

$$G = E \cdot (1 - W - P) \cdot F$$

where variables are defined as below.

E	total electricity demand (TWh)
F	emission factor for electricity excluding wind and solar ($MtCO_2/TWh$)
W	share of wind in the electricity mix
P	share of solar in the electricity mix

Attribution of total emissions reduction to four factors, E, W, P, F is calculated using Taylor series of the function G. Hence, the change in emissions between reference(0) and mitigation is

$$\begin{aligned}\Delta G = \; & G(E, W, P, F) - G(E_0, W_0, P_0, F_0) \\ & = (1 - W_0 - P_0)\, F_0\, \Delta E - E_0 F_0 \Delta W - E_0 F_0 \Delta P + E_0 (1 - W_0 - P_0) \Delta F + O(\Delta^2)\end{aligned}$$

The higher order term, $O(\Delta^2)$, is allocated in proportion to the first order allocation.

5.10.2 Efficient building envelopes

GHG emission by building envelope is defined by a function G,

$$G = E \cdot F$$

where variables are defined as below.

E	total energy demand for residential heating (TWh)
F	emission factor for residential heating ($MtCO_2/TWh$)

Attribution of total emissions reduction to two factors, E, F is calculated using Taylor series of the function G. Hence, the change in emissions between reference(0) and mitigation is

$$\Delta G = G(E, F) - G(E_0, F_0) = F_0\, \Delta E + E_0 \Delta F + O(\Delta^2)$$

The higher order term, $O(\Delta^2)$, is allocated in proportion to the first order allocation.

5.10.3 Efficient lighting

GHG emission by lighting is defined by a function G,

$$G = E \cdot F$$

where variables are defined as below.

E	total lighting electricity demand (TWh)
F	emission factor of electricity ($MtCO_2$/TWh)

Attribution of total emissions reduction to two factors, E, F is calculated using Taylor series of the function G.

Hence, the change in emissions between reference(0) and mitigation is

$$\Delta G = G(E, F) - G(E_0, F_0) = F_0 \, \Delta E + E_0 \Delta F + O(\Delta^2)$$

The higher order term, $O(\Delta^2)$, is allocated in proportion to the first order allocation.

5.10.4 Transport

GHG emission by car transport is defined by a function G,

$$G = E_{2012} \, (L/3.6)(1 - h_t)(1 - h_w)(1 - h_x) \, \{(1 - m)k + m(1 - h_e)z\}$$

where variables are defined as below.

E_{2012}	Energy efficiency of transport in 2012 = 2.219 (PJ/billion km)
L	distance driven
h_t	efficiency improvement by fuel-efficient tires
h_w	efficiency improvement by light-weight materials
h_e	efficiency improvement by EV = 0.78
h_x	efficiency improvement by other factors

m market share of EV

k emission factor for regular car

z emission factor for electricity

Data of L, h_t, h_w, h_e, m and z are given for each scenario.

1. First, determine other efficiency improvement, hx, using equation (1), for each scenario.

   $$h_x = 1 - J/\{E_{2012}L\,(1-h_t)\,(1-h_w)(1-mh_e)\} \equiv \quad 1-(1-h_o)/[(1-h_t)\,(1-h_w)(1-mh_e)]$$

2. Second, calculate emission factor for regular cars for each scenario. This is done by the equation, (Total emissions (IEA-ETP2015) – EV emissions)/(Energy demand of regular cars/3.6) with a unit of $MtCO_2/TWh$.

   Here, EV emissions = emission factor of electricity * energy demand of EV $= \mathrm{z}\,E_{2012}(1/3.6)(1-h_t)(1-h_w)(1-h_x)(1-h_e)\,L\,m$

   Energy demand of regular car = $E_{2012}(1-h_t)(1-h_w)(1-h_x)\,L\,(1-m)$

   Emission factor of regular car is basically the emission factor of fuel, which is dependent on fuel mix.

Attribution of total emissions reduction to the various factors is calculated using Taylor series of the function G.

Hence, the change in emissions between reference(0) and mitigation is

$$\mathrm{G}(L,\ h_t,\ h_w,\ h_x,\ m,\ k,\ z) = G(L,\ h_t,\ h_w,\ h_x,\ m,\ k,\ z)_{\,0} + (\partial G/\partial L)dL + (\partial G/\partial h_t)dh_t + (\partial G/\partial h_w)dh_w + (\partial G/\partial h_x)dh_x + (\partial G/\partial m)dm + (\partial G/\partial k)dk + (\partial G/\partial z)dz + O(\Delta^2)$$

In the final results the efficiency improvement by other factors and the emission factor for the regular car are combined in the category “Other”. The category “Market share electric cars” describes the simultaneous effect of the market share of EV, the efficiency improvement by EV and the emission factor of electricity.

The higher order term, $O(\Delta^2)$, is allocated in proportion to the first order allocation.

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