EUCALC

Explore sustainable European futures

Expert consultation on manufacturing, material use and raw materials

D3.4

September/2018

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730459.

Project Acronym and Name	EU Calculator: trade-offs and pathways towards sustainable and low-carbon European Societies - EUCalc
Grant Agreement Number	730459
Document Type	
Work Package	3
Document Title	Expert consultation on manufacturing, material use, and raw materials
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Release date	
Distribution	*Public:* *All involved authors and co-authors agreed on the publication.*

Short Description
This report summarises the activities and discussions of the Expert consultation workshop on manufacturing and production. *It covers the input given at the event by the organisers as well as feedback and recommendations provided by participants on the modeling approach, key assumptions on manufacturing sectors, comprehensive data sources and general trends in industry, such as circular economy or Industry 4.0.*

Quality check	
Name of reviewer	**Date**
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O. Mwabonje, Imperial College London	**28.09.2018**
J.P Kropp, PIK	**8.10.2018**

Statement of originality:

This deliverable contains original unpublished work except where clearly indicated otherwise. Acknowledgement of previously published material and of the work of others has been made through appropriate citation, quotation or both.

EUCalc policy of personal data protection in regard to the workshop

EUCalc defined the procedures in order to reply to ethical requirements in Deliverable 12.1 (Ethics requirements – procedures and criteria to identify research participants in EUCalc – H – Requirements No. 1). All procedures in relation to the co-design process, in particular the Stakeholder mapping, the implementation of the workshops and the follow-up of the workshops, follow these procedures. The informed consent procedure in relation to the workshops is based on D9.2 “Stakeholder mapping” and D9.4 “Method for implementation of EUCalc co-design process”. The originals of the signed consent forms are stored at the coordinators’ premises without possibility of access of externals. Scans of the informed consent forms are stored on the internal EUCalc file storing system

Table of Contents

1 Executive summary

This report summarises activities and conclusions from the "manufacturing, material use and raw materials" Expert Stakeholder workshop, within the framework of the EU Calculator project, held in Vienna on 10th July 2018. It covers the main findings and discussion points raised during the workshop as well as providing analysis on how observations and recommendations from the Expert Stakeholders who attended the workshop are to be integrated into the ongoing work on this sector.

Prior to the workshop each Expert Stakeholder was provided with "pre-read" material, which outlined the methodology, main assumptions, and data sources identified.

The workshop included a series of focused dialogues and work groups to confirm and/or question the following elements of the work, including:

- The modelling approach (key target group, sector interfaces)
- Industrial sectors covered
- Lever choices and ranges
- Key trends and developments (circular economy, digitalisation, carbon leakage)
- Resource availability and conflict of use (e.g. biomass)

A total of 18 external Experts Stakeholders from companies and industrial associations (steel, cement, paper, chemicals), research organizations in the field of economics, members of energy agencies participated at the workshop (see annex 2 for a list of participants).

2 Introduction

The goal of the European Calculator (EUCalc) project is to test low-carbon transformation pathways on the European and member state scale. This project will develop a novel and transparent open source model combined with a Transition Pathways Explorer, which is an online tool providing instant results from the EUCalc model runs.

With EUCalc tool, European and national policy-makers, businesses, NGOs, innovators, and investors will be able to create online and in real-time, their own pathways and compare them to other integrated pathways. The results will enable EU policy-makers to support the energy, emissions and resources debate on a low carbon transition.

The development of the EUCalc tool is a module-based process. Each work package of the project produces one or multiple modules that are linked together to form a global model. This allows each module to work independently, providing the necessary flexibility and integration of the EUCalc tool development (Fig.1).

The manufacturing and production module (hereinafter referred to as manufacturing module) is linked to the lifestyle, food production, transport, and buildings modules. It is from these aforementioned modules that demand for new products that need to be produced is relayed to the manufacturing module. The trade balance of products and materials determines the linkage between manufacturing and trade modules. The energy demand of the manufacturing module is an input for the energy supply module as well as for the land module in relation to biomass demand.

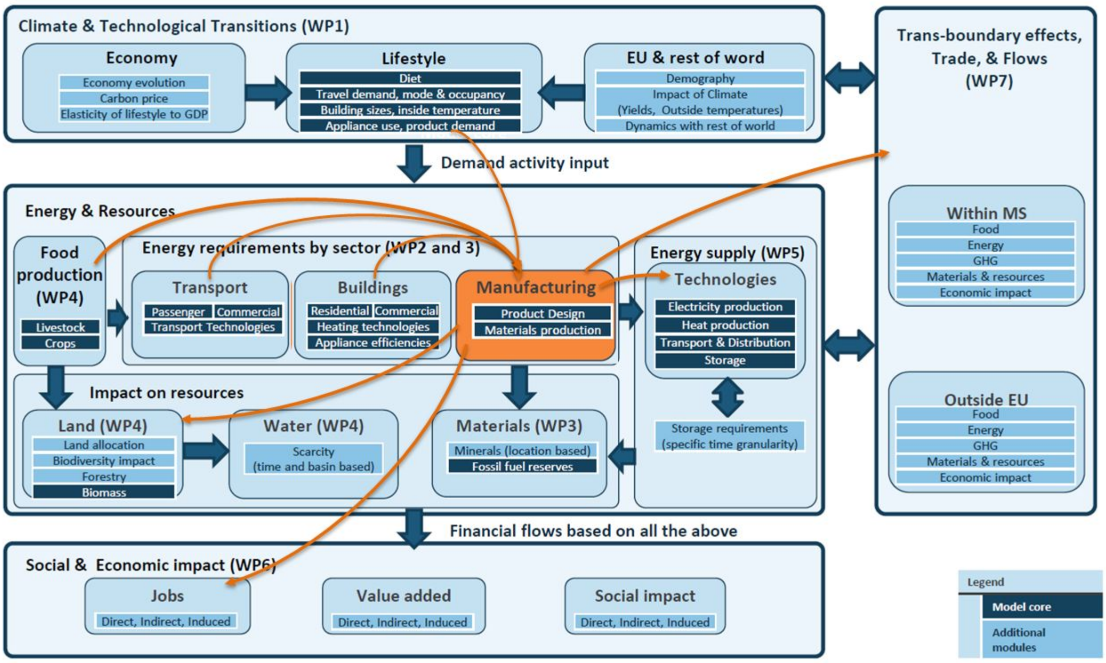

Fig. 1 Modular structure of the European Calculator Model

2.1 Objectives of the Expert consultation

The objective of the facilitated Expert consultation was to introduce the philosophy of the EUCalc, current results and achievements of the modelling work in the EUCalc project to a cross-section of Expert Stakeholders, in order to validate and/or to critically examine the underlying methodology, the levers and levels of ambition within the manufacturing module through a process which underpins the core principle of co-creation across all of the EUCalc work packages.

2.2 Identification and selection of Expert Stakeholders

An Expert selection process was designed to ensure a reasonably balanced range of respected expertise and scientific opinion concerning the critical aspects of the EUCalc manufacturing module.

The workshop organizing team mapped and sent invitations to a total of 139 Stakeholders, from civil society, academia, public and private sector who possess the relevant expert background and/or experience to contribute a thorough understanding, evidence and quantitative input regarding the future of the European production and manufacturing (steel, cement, paper, and chemicals). Invited Stakeholders come from all over Europe and represent expertise from various industrial settings across Europe.

The Experts were invited specifically to attend the workshop, but also - in case not available - to take part in subsequent exchange planned under the EUCalc's Call for Evidence online consultation process. In areas where less diversity in expertise was observed during the workshop, the EUCalc team has undertaken additional, remote consultations.

2.3 Facilitation and structure of the workshop

The workshop was professionally facilitated and designed with three distinct components namely; i. plenary scene setting and introduction, ii. presentation of the EUCalc model and the specific components of the manufacturing module and then iii. break-out group discussions to allow Expert Stakeholders to review and report back on key questions and topics.

The logical flow of the workshop meant that the process proceeded from the general big picture scene-setting elements, including a keynote speaker, through a demonstration of the EUCalc model - using the Global Calculator as a proxy - and a detailed description of the particular elements of the manufacturing module and its specific issues. This was then followed by structured and facilitated break-out sessions, which allowed discussion and review of both pre-identified key questions and any new questions which have emerged during the discussions by Expert Stakeholders working in smaller groups.

With the assistance of designated rapporteurs, the Experts were encouraged to investigate and discuss 4 sets of questions in 4 breakout groups, to cross-examine reasoning and provide evidence and quantitative responses. The full scope of inputs was facilitated through a mechanism of world cafe, while concluding plenary session created a space for aggregation of provided estimates and judgments.

In relation to the keynote speaker, this was introduced as an idea to the structure of the workshop to fill 3 specific functions: a) to have an opening speaker whose work is known to be future-orientated, boundary-breaking and inspirational or at least best practise in their field, in order to set the tone for a workshop, which wishes to discuss values for lever settings out to 2050, b) to be a draw for potential invitees in terms of the reputation and profile of the speaker and last but not least c) given this profile, to help with the social media profile of EUCalc by linking the Keynote speaker to the EUCalc. These speakers are not necessarily expected to give critical scientific input to the workshop.

3 Description of the Expert consultation workshop

3.1 Consultation component i. Setting the scene

The Expert consultation was opened with a general presentation by Hannes Warmuth of ÖGUT and Judit Kockat of BPIE about the EUCalc project and the modelling approach. In their presentation, they explained the logic of the approach and how the Transition Pathway Explorer will allow the user to interactively use it and visualize the results of each selected scenario in real-time.

Their presentation was followed by the contribution of the invited keynote speaker Martha Rehnberg from DareDisrupt, serving as a member of the EU High Level Industrial Roundtable “Industry 2030”, who talked about the impact of disruption in industry and provided a vision of the future role of Industry 2050.

This was followed by a Q&A session about the future of the European Industry with the sister projects of EUCalc: REINVENT and INNOPATHS. The projects were presented by Mariësse van Sluisveld from REINVENT and Tadeusz Skoczkowski from INNOPATHS.

In the final segment, Hannes Warmuth and Stefania Tron of ÖGUT focused on the specific topic of the workshop and presented the modelling approach adopted for the manufacturing module of EUCalc, the scope of the analysis, including a specific example about the future of iron and steel industry in Europe (see Section 3.2.).

3.1.1 Contributions from invited speakers

In her keynote contribution “Rethinking the European Industry“, Martha Rehnberg from DareDisrupt presented a number of provocative examples to illustrate value shifts and ways in which digitalisation can and is transforming the European industry highlighting aspects such as *democratization, decarbonisation and responsible disruption* in particular:

- Democratization. It is at the core of digital technology, allowing almost everyone to have access to industry by democratizing means of production (e.g. 3D printing, Leon McCarthy prosthetic hand).
- Decarbonisation. New business models are emerging that are circular, decarbonized, fully efficient and they bring a bold vision of the future of production; take as an example using 3D printing to produce shoes by means of which retail shops are becoming factories. But this is not only about production and transportation or reducing inventory of warehouses which has a strong carbon footprint, but it is also about moving away from ownership models whereby one does not need to own shoes but to have access to it. Moreover, certain leaps are also taken in the direction of

using robotics to filter all kinds of waste from the ocean and shoes of the future could be created from this ocean plastic waste.

- Responsible disruption. Digitalization changes the rules of the game. It may disrupt our style of working and how we produce and therefore has consequences for human and civil rights (e.g. Cody Wilson's Liberator gun). Thus, policy makers have to think and act in new ways to steer economies in a much more responsible way.

It is not 3D printing alone but the digitalisation of businesses and industrial processes allows us to think of multiple industries in a combined way. When something is digital it can communicate with each other: one technology alone is uninteresting and new markets can only emerge via a combination of technologies (e.g. Tesla for energy storage and solar tiles). Forecasting the future outlook of industry, therefore, needs to consider ecosystems approach, partnerships, etc. Digitalization also challenges us to think exponentially in our forecasting models given that rapid growth of technology is actually accelerating progress across a number of domains making the future unfold, against our intuition, not linearly but exponentially.

We are also seeing a value shift, whereby energy is no longer only a resource, but there is a shift towards thinking about energy as technology and software. Peer to peer solar energy trading, combining blockchain, smart contracts, that allow peers to decide and define how to trade energy also speaks of the value shift and societal changes enabled by technology.

The presentation of Martha Rehnberg was followed by presentations about the EUCalc's sister projects REINVENT and INNOPATHS.

Mariësse van Sluisveld, researcher at PBL (Netherlands Environmental Assessment Agency) and member of the REINVENT project team, provided some insights into the project's research of decarbonisation and innovation pathways for industry by 2050. The project focuses on some critical industries, e.g. paper, plastics, steel, meat and dairy production, and aims to understand innovation and low carbon transition looking at the technological as well as non-technological factors at the European level. Innovation pathways are studied in terms of their alignment with the Paris agreement and they include many aspects such as demand reduction, electrification, carbon capture and storage, finance, etc.

Tadeusz Skoczkowski, professor at the University of Warsaw and member of the INNOPATHS project team, presented the INNOPATHS's work on innovation pathways for low carbon transition. The INNOPATHS's project activities include looking at the challenges for decarbonisation, conducting a detailed assessment of low-carbon technologies, their uncertainties, future prospects and system characteristics for four national case studies, namely Germany, Italy, Poland, and the UK. Based on this analysis INNOPATH will propose policy and innovation system reforms that will help the EU and the Member States meet their greenhouse gas emission reduction targets. Although concentrating on technologies, the work of INNOPATHS includes as well added values, environmental and social aspects.

The discussion which followed regarding the future of the European Industries focused on the following points:

- EU should be seen as a global leader in innovation and industrial production, assuming a model somewhere between the US e.g. Silicon Valley approach and a state-led economies top-down approach that exists in other parts of the world.
- Traditional industries in Europe are facing increasing global competition (e.g. steel, chemicals, and cement) and also increasing competition in new products/markets (e.g. growing competition from China in renewables).
- Industrial Policy/Strategy: based on a concern about the past neglect of industrial development, the renewed EU Industrial Policy Strategy 2017 brings together existing and new horizontal and sector-specific initiatives. EU foreign policy is important in these regards as well in terms of access to energy and mineral deposits. Carbon leakage and thus, the EU emissions trading system (EU ETS) was identified as a significant risk for industrial competitiveness unless mitigation measures are not taken.
- Industry has a very important position in planning low carbon transition; it takes a lot of effort to decarbonize industries (e.g. change production capabilities, fuel switching) and this would require public support, including financial support.

3.2 Consultation component ii. Description of the manufacturing and production module

After the contribution from the invited speakers, the manufacturing module of the EUCalc was introduced by Hannes Warmuth and Stefania Tron from ÖGUT. The detailed description of the module was provided to Experts in advance in a pre-read document.

The pre-reading material is a document for participants to familiarize themselves with the modelling philosophy, the identified and selected levers for manufacturing sectors and some of the key topics that will be discussed during the workshop. Participants were requested to read the documents before the workshop. The content of the pre-reading document is reported in the following sections (3.2.1- 3.2.6).

3.2.1 Introduction to the manufacturing and production module

The aim of the manufacturing and production module is to provide projections based on Expert validated lever and level of ambition settings until 2050 for each European country (EU28 + Switzerland) for the following:

- Direct CO2 equivalent emissions in the industry sector [Mt CO2]
- Energy demand (stratified by energy carrier) [TWh]

- Material production [Mt]
- The overall cost (capex and opex) [€]

The indirect emissions related to the manufacturing module are modelled by other modules, e.g. emissions associated with the electricity consumption in the industry are calculated by the energy module (WP5) and emissions associated with freight transport are calculated by the transport module (WP2.2).

The Manufacturing module covers industries responsible for a large share of CO_2 equivalent emissions in Europe. To identify these industries we collected data from the European Environment Agency (see tables below) about emissions from fuel combustion and industrial processes. The CO_2 equivalent emissions in EU28 for the different industries in 2015 are shown in Fig. 2. The six most carbon-intensive industries are iron and steel, cement, chemical, ammonia, food, and beverages, as well as pulp and paper. These industries are modelled in detail in EUCalc (except food and beverages, which is partly modelled in the Agriculture module). The remaining industries will be grouped together in a general “other industries” block.

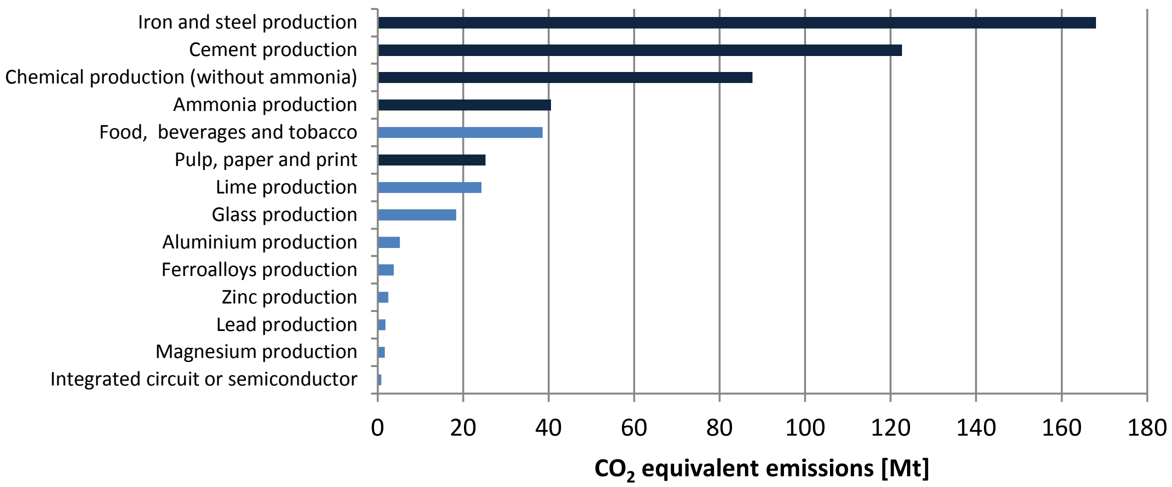

Fig. 2 CO_2 equivalent emissions in 2015 in EU28, the industries modelled in the manufacturing module are in dark blue (ÖGUT based on EEA data)

The selected industries are also the most energy-intensive ones, as can be seen from Fig. 3, which shows their energy consumptions in 2015.

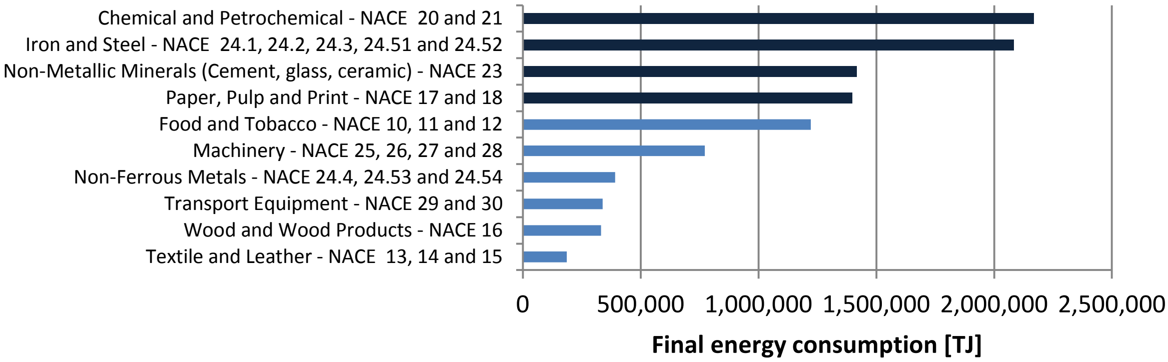

Fig. 3 Total energy consumption in 2015 in EU28, the industries modelled in the manufacturing module are in dark blue (ÖGUT based on Eurostat data –complete energy balance nrg_110a)

3.2.2 Modelling approach

Using the product demand per sector, the tons of material per product, the fuel mix employed, the Manufacturing module produces as outputs the CO2 equivalent emissions from the most carbon-intensive industries (steel, cement, chemicals, paper), the total energy demand divided by energy carrier, the total material production, as well as the overall cost associated.

The calculations can be divided into 4 subsequent steps, which are shown in Fig.4:

1. **Product level**: the yearly demand for new product is received as an input from other modules, e.g. projected requirements for new cars and trucks from the transport module (WP2), appliances and buildings from the building module (WP2), packaging from the lifestyle module (WP1), and fertilizer from the agriculture module (WP4). A completed list of the products considered is provided in Tab. 1. Accounting for the net import rates of these products provided by the trade module (WP8) the manufacturing module calculates how many of these products are manufactured in each European country. The quantities of materials (i.e. of steel, cement, chemicals, paper) required for their production is assessed based on the product composition (e.g. x kg of steel in a car).
2. **Material level**: from the material demand we estimate the material production based on the self-sufficiency rate (net import) of each material. In case the availability of raw materials is insufficient to produce these materials a warning will be provided. For each manufacturing branch, the production technology share (e.g. primary and secondary route share for steel making) was assessed and based on this the amount of material produced with each technology is calculated.
3. **Energy and feedstock level**: the manufacturing module calculates the energy and feedstock demand based on the amount of material produced and the fuel mix employed by each technology of each industry branch. This is obtained by multiplying the amount of material produced with a given technology by the specific consumptions

[TWh/Mt of material] of energy and feedstock of each energy carrier (see the list of energy carriers in Tab. 1).

4. **Emission level**: the CO_2 equivalent emissions are obtained by summing the direct emissions produced by fuel combustion and the process emissions (emissions associated with the chemical or physical transformation of materials excluding the fuel combustion, e.g. calcination in cement production). The fuel combustion emissions are the results of the multiplication of fuel consumptions by the specific fuel emissions [Mt of CO_2e /TWh]. The process emissions are obtained by multiplying the amount of material produced with a given technology by the specific process emissions of this material [Mt of CO_2e /Mt of material].

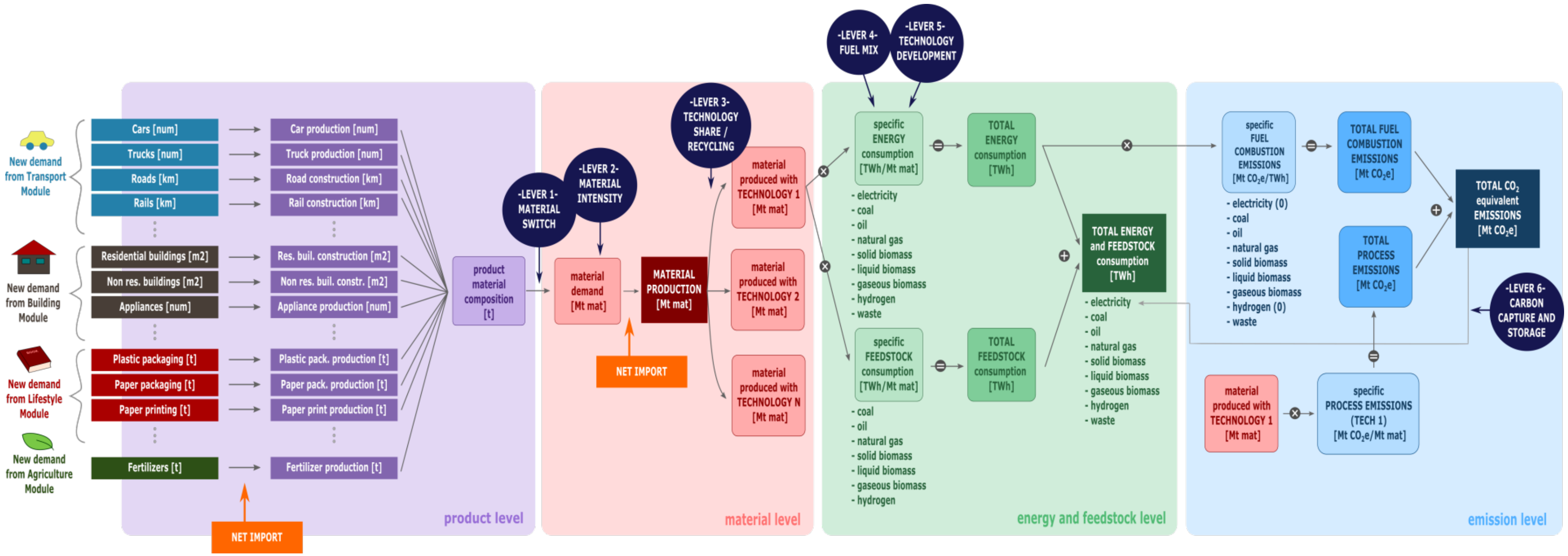

Fig. 4 industry calculation tree

3.2.3 Scope of the analysis

The comprehensive/extensive list of products, the industries, the technologies and the energy carriers taken into accounts in the manufacturing and production module are listed in Tab. 1

Tab. 1 Scope of the manufacturing module

NEW PRODUCT DEMAND	
From Transport Module (WP2) - Int. combustion engine cars [num] - Int. combustion engine trucks [num] - Fuel cell cars [num] - Fuel cell trucks [num] - Electric cars EVs[num] - Electric trucks [num] - Ships [num] - Trains [num] - Planes [num] - Trolley-cables [km] - Roads [km] - Rails [km] **From Agriculture Module (WP4)** - N-fertilizers [t]	**From Building Module (WP2)** - Residential buildings [m2] - Non-residential buildings [m2] - Insulation residential buildings [m2] - Insulation non-residential buildings [m2] - Fridges [num] - Washing machines [num] - Dishwashers [num] - District heating pipes [km] **From Lifestyle Module (WP1)** - Plastic packaging [t] - Paper packaging [t] - Paper printing and graphic [t] - Paper sanitary and household [t]
INDUSTRIES AND TECHNOLOGIES	**ENERGY CARRIERS**
• **Steel [Mt]** - Blast furnace-basic oxygen furnace (BF-BOF) [%] - Scrap- Electric arc furnace (scrap-EAF) [%] - Direct reduced iron - electric arc furnace (DRI-EAF) [%] - Hisarna[%] • **Cement [Mt]** - Dry kilns [%] - Wet kilns [%] - Geopolymers [%] • **Ammonia [Mt]** • **Other chemicals [Mt]** • **Paper and pulp [Mt]** - Wood pulp [%] - Recycling [%] • **Other industries [Mt]**	- Coal [TWh] - Oil [TWh] - Natural gas [TWh] - Solid biomass [TWh] - Liquid biomass [TWh] - Gaseous biomass [TWh] - Electricity [TWh] - Hydrogen [TWh] - Waste [TWh]

3.2.4 Choice of levers

Abatement of $C0_2$ equivalent emissions in the module can be obtained by following a number of emission mitigation strategies. Hereafter we have identified the most relevant actions that need to be taken in order to significantly reduce emissions in the industry sector by 2050:

1. Substitution of materials used in products (e.g. using more timber and less steel and cement in buildings)

2. Reduction of the material intensity (e.g. replacing common steel with high strength steel)
3. Change of technology in the material production (e.g. switching from the primary route to the recycling route or to innovative technologies)
4. Switch to green energy carriers in the material production (e.g. from fossil fuels to biomass and to hydrogen, considering the limited availability of these energy carriers)
5. Increase of energy efficiency of each technology
6. Use of CCS to capture waste carbon dioxide (considering the storage potential of each European country)

Each of these actions constitutes a lever in the module to reduce $C0_2$ equivalent emissions. The magnitude of this reduction is expressed in the ambition level, which ranges from a minimal to an extraordinarily ambitious effort to tackle climate change. The levers (shown in Fig. 4) are:

1. **Material switch** [% of material replaced by another in the most relevant products]
2. **Material intensity** [% of the decrease in material demand due to smart design, use of high strength materials, 3D printing]
3. **Technology share/Recycling** [% of material produced with a given technology in each industry]
4. **Fuel/energy carrier mix** [% of energy consumed by each energy carrier(electricity, coal, oil, gas, biomass, waste, and hydrogen) in each technology]
5. **Technology development** [% of the decrease in energy consumption due to energy efficiency measures for each technology]
6. **Carbon capture and storage** [% of CO_2 equivalent emissions captured with CCS in each industry]

3.2.5 Definition of ambition levels

For the sake of brevity, the ambition levels of each lever are provided in Annex 6.3. The lever settings are determined based on a literature review and were discussed in the Expert consultation. Following the Expert consultation, an additional review has been carried out to clarify and refine the ambition levels based on issues/opinions which came up in the workshop and in order to assess the scientific underpinning of any claim or suggestion. At this stage, the core levers and their ambition levels are considered sufficiently robust to provide solid inputs for the beta version of the European Calculator, however, there is the possibility for additional value refinement following the Call for Evidence.

For each lever we propose 4 levels of ambitions to reduce emissions by 2050. The 4 levels are defined as:

- **LEVEL 1: Business as usual**
  This level contains projections that are aligned and coherent with the observed trends.
- **LEVEL 2: Ambitious but achievable**
  This level is an intermediate scenario, more ambitious than business as usual but not reaching the full potential of available solutions.

- **LEVEL 3: Very ambitious but achievable**
  This level is considered very ambitious but realistic, given the current technology evolutions and the best practices observed in some geographical areas.
- **LEVEL 4: Transformational breakthrough**
  This level is considered as transformational and requires additional breakthrough and efforts such as a very fast market uptake of deep measures, an extended deployment of infrastructures, major technological advances, or strong societal changes, etc.

3.2.6 Questions to the Expert Stakeholders

3.2.6.1 Calculation logic and scope of analysis

The following list of questions was sent to the Experts prior to the workshop and then addressed during the plenary and break-out sessions:

- Are the aims and scope of the EUCalc modelling philosophy clear?
- What do you think of the model approach adopted by the manufacturing module?
- Does the scope of analysis of the manufacturing module completely cover most relevant carbon-intensive industries?
- Do you think that we comprehensively covered the most carbon-intensive industries?
- Should we add other relevant production technologies in the modelled industries?
- Do you think that the list of energy carriers is complete?
- Do you agree with the selection of the most important levers?
- Do you think our choice of levers is coherent and comprehensive?
- Are there any other important levers missing on the list? Are there irrelevant levers you think we should remove from the list?

3.2.6.2 Ambition levels and future scenarios

These questions were addressed to break out groups during the consultation:

- Do you think that we covered the main material switches?
- Is the substitution rate represented in the ambition levels of the material switch lever realistic? Too ambitious? Not ambitious enough?
- Is the decrease in material use represented in the ambition levels of the material intensity lever realistic? Too ambitious? Not ambitious enough?
- How much do you think is the share of recycled materials going to change?
- Is the trend represented in the ambition levels of the technology share lever realistic? Too ambitious? Not ambitious enough?
- Is the trend represented in the ambition levels of the energy carrier mix lever realistic? Too ambitious? Not ambitious enough?
- Is the energy efficiency improvement represented in the ambition levels realistic? Too ambitious? Not ambitious enough?
- Is the share of emissions captured represented in the ambition levels realistic? Too ambitious? Not ambitious enough?

3.3 Consultation component iii. Discussion and recommendations

The third segment of the workshop was dedicated to getting input from Expert Stakeholders about the relevance of levers and the accuracy of the ambition levels. The Experts were divided into 4 groups in order to focus on the ambition levels of specific levers:

- Group 1: ambition levels of material switch and material intensity levers
- Group 2: ambition levels of technology share/recycling lever
- Group 3: ambition levels of fuel/energy carrier mix lever
- Group 4: ambition levels of technology development and carbon capture and storage levers

To get as much input as possible and cover all the levers a stripped down world cafe1 methodology was adopted. At the end of the workshop, the comments of the Experts from each discussion table were summarized and presented to the audience and are listed hereafter (Section 3.3.2) together with the comments concerning the module approach and scope (Section 3.3.1).

Below every input and /or question, we also present in italic the clarification provided by the EUCalc team during the workshop and information about the workshop follow-up work on the manufacturing and production module.

3.3.1 Expert Stakeholder feedback on manufacturing and production module scope and lever choice

All the levers were confirmed to be relevant and the Experts did not propose any new lever.

Concerning the choice of industries, the following Expert Stakeholder comments and reflections from the EUCalc team have been captured. In some cases, the comments represent very narrow sectoral interests and in others extremely broad big picture feedback. The EUCalc team has endeavored here to capture and respond - where possible - to all inputs:

- Expert input: consider adding lime, glass, ceramics and aluminium production. This is because in different countries the respective gross value added ratios are different and the circumstances can be slightly different. In addition, because these are also energy-intensive processes (in terms of material units).

  EUCalc reflection: industries modelled in the manufacturing module have been selected based on their significant share in the total energy demand and emissions at the European level (see Fig. 2 and 3). As can be seen in Fig.2 lime and glass productions are responsible for a minor amount of emissions in Europe compared with steel, cement, chemicals, and paper productions. Industries which are not individually modelled will be included under the section 'other industries' in order not to underestimate the total energy consumed and the total emission produced by the industry sector. The EUCalc is a tool intended to explore trade-offs and synergies across economic

[1] http://www.theworldcafe.com/key-concepts-resources/world-cafe-method/

sectors; it does so by exploring as many processes as possible to provide robust results in terms of potential low carbon development pathways per European country until 2050. Beyond 2050 only the most essential processes are projected because of increasing uncertainties. We will add other manufacturing processes to the manufacturing module if we estimate that their inclusion will have a relevant impact on the results.

- Expert input: for the chemical products consider adding a few more individual processes such as methanol, ethylene, and chlorine. Methanol and ethylene because, depending on the product, there can also be process switches and hydrogen can also play a role, chlorine because of the high current intensity.

  EUCalc reflection: we will evaluate if this addition of resolution would significantly alter the results of the model.

- Expert input: the depiction of refineries should be detailed somewhere. They tend to be forgotten in the energy system models, but they play an extremely important role in the reduction of fossil fuels (e.g. production of carbon-containing feedstock for the chemical and pharmaceutical industries as well as bitumen for the construction industry). Hydrogen also plays a role here as input material.

  EUCalc reflection: the energy demand in term of coal, oil, natural gas, and hydrogen (including both fuel and feedstocks) of each industry is provided to the energy module (WP5). This module depicts the production and refinement of coal, oil, natural gas, and hydrogen and gives a warning in case in some scenarios the supply cannot match the demand.

- Expert input: how will you model ammonia production? There are ongoing discussions regarding the use of ammonia as a form of energy storage for renewables (conversion of electricity to hydrogen, and then to ammonia, and back).

  EUCalc reflection: the production of ammonia is modelled, because it is a very carbon-intensive process. The possibility to consider ammonia as a form of storage for energy in the model is currently being evaluated and discussed within the energy module of the EUCalc.

- Expert input: not all sectors/industries are covered in the model, which creates a risk of underestimated demand.

  EUCalc reflection: in order to guarantee that the energy demand will not be underestimated, industries which are not individually modelled will be included in 'other industries'.

- Expert input: regarding electrification of industry, where does this 100% of renewable energy comes from? How will renewable energy be distributed across sectors? What impact will it have e.g. on wood processing industry? For instance, wood can stay in buildings for 100 years, rather than burn it.

  EUCalc reflection: the electricity used in industry is not necessarily coming only from renewable sources. In the manufacturing module the demand of electricity is estimated and then this demand is provided to the energy module. How this energy is produced depends on the user choice of the ambition level of the lever concerning renewable energy. If the ambition level is low just a minor part of the energy will be produced with renewable energy sources. In terms of biomass, its distribution across sectors is currently being *discussed and evaluated as part of the land use and agriculture module (WP4). This could be represented either through a lever that will enable setting priority between the different uses of biomass or by letting the model driving the biomass towards the different markets, such as the previous Calculators. Please see Del 4.2 for more details.*

Concerning the choice of energy carriers it was suggested to:

- Expert input: segment coal into hard coal and brown coal (lignite) as in eastern European countries brown coal still plays a role in the industry.

  EUCalc reflection: we are evaluating a distinction between hard coal and lignite in the model. The possibility of segmenting coal will be discussed with the energy module.

- Expert input: segment waste into residential and industrial waste as industrial waste has different calorific values and could be very different depending on the industry.

  EUCalc reflection: we will evaluate if to segment waste into residential and industrial waste, also considering that it would create a feedback loop for the manufacturing module. The feedback loop is due to the fact that industrial waste would be both an input (waste burnt as fuel) and an output (waste generated during the industrial processes) for the module. The European Calculator, being able to provide an instantaneous response, is able to handle a limited number of feedback loops.

- Expert input: differentiate biomass by origin (cultivated biomass, residues) because biomass and potential limitations are becoming more and more of an issue. It is suggested to differentiate the gaseous biomass into biogas and biomethane (H_2-enriched biogas), due to the calorific value of biomethane which is higher than biogas and a potential substitute for natural gas.

  EUCalc reflection: we are currently discussing this issue within the land use and agriculture module (WP4) as we aim to differentiate as much as possible the biomass demand especially concerning the biomaterial demand. The idea is to further differentiate the liquid biomass in oil and ethanol, and the solid biomass in wood, miscanthus, and hemp, but we will evaluate also the possibility to differentiate the gaseous biomass into biogas and biomethane.

- Expert input: add synthetic fuels (power-to-gas, power-to-liquid), they will play a role from 2035 play in some scenario

  EUCalc reflection: we will discuss the relevance of synthetic fuels by 2050 with the transport module (WP2.2) and the energy module (WP5) and will decide where and how to include them.

- Expert input: biomass is a very limited resource, how do you consider that concerning the use of biomass in iron and steel production?

  EUCalc reflection: the total demand of biomass from the manufacturing module is an input for the land use and agriculture module (WP4). The land use and agriculture module calculates the available land and the necessary imports from the rest of the world or other European Countries to see if it possible to satisfy the biomass demand from the manufacturing module as well as from the other modules.

- Expert input: are you considering hydrogen in iron production? There are already ongoing projects, one in Sweden and one in Germany, using hydrogen and moving away from natural gas (price volatility).

  EUCalc reflection: yes, hydrogen is considered as an energy carrier for the iron and steel industry and we expect it to play a significant role in this industry in the future, especially in the DRI (direct reduced iron) technology.

Concerning the model logic:

- Expert input: so far, you seemed to have modelled only pure processes (i.e. process heat and mechanical energy and electrolysis). Of course, in the non-energy-intensive industries, they play a bigger role and they have different drivers than production volumes. These include room heating, building services, lighting, on-site logistics including conveyor belts, other mechanical energy (pumps, pumping, etc.), IT and process control and environmental protection (filter systems, afterburning) etc.

  EUCalc reflection: space heating and lighting are covered in the buildings module (WP2.2). The other processes requiring electricity are included in the electricity demand from each industry.

- Expert input: regarding the production quantities, are the data comparable for all countries or do you want to map these via production indices etc.? We already know how difficult that is in D and CH. Especially since in most cases (for example steel) there are also internal differentiated products.

  EUCalc reflection: the data for production quantities is based on European statistics (EUROSTAT) and therefore considered reliable.

- Expert input: regarding chemicals, it is recommended not to lump together tons of methanol, titanium dioxide, and polymer plastics. An alternative is to differentiate or to use production indices.

  EUCalc reflection: yes, it is intended to eventually split chemicals in more products. The issue has been also raised when developing the technology matrix (WP1). However, it is of a lower priority and will be decided at a later stage.

Regarding the cost assessment:

- Expert input: do you calculate full costs or differential costs in each scenario compared to a reference scenario? In the first case, the depiction of the existing capital stock (especially in industry) is extremely difficult, expensive and always very inaccurate

  EUCalc reflection: how costs will be calculated is still under evaluation (if we will assess full costs or differential costs). Anyway, we will calculate for each industry capital and operation costs, as well as the cost associated with the fuel and electricity demand.

- Expert input: is the price for CO_2 modelled?

  EUCalc reflection: this is still under consideration and options to include carbon price are being discussed by all relevant WPs, including WP7 (transboundary effects).

About transparency and flexibility:

- Expert input: considering the EUCalc's political and social impact, transparency about boundaries of the project (e.g. static and not dynamic model) and back-up documentation (assumptions, references, data) is much appreciated to allow users to interpret results correctly.

  EUCalc reflection: the model is open source and an exhaustive documentation will be provided in order to allow also the non-expert user to understand the logic of the model and the assumptions behind it. The references for the assumptions and the sources of data used in the model will also be provided.

- Expert input: with a view on disruptive technologies, it is preferable to have a modelling structure that allows relatively quick reviews, updates and changes of assumptions periodically to make sure that EUCalc can be used to assess the impact of new technologies and products.

  EUCalc reflection: the structure of the model is flexible and allows for future changes. The data and the assumptions are not hard-coded but are an input for the model. In this way, they could be easily modified in the future.

3.3.2 Expert Stakeholder feedback on ambition levels

Concerning ambition levels, the following Expert Stakeholder comments and reflections from the EUCalc team have been captured. In some cases, the comments represent very narrow sectoral interests and in others extremely broad big picture feedback. The EUCalc team has endeavored here to capture and respond - where possible - to all inputs:

- Expert input: it is important to define clearly whether the ambition is set in Europe and worldwide, or at lower national or state-grouped levels because depending on that learning curves and thus cost structures can change. In your assumptions for levels do you look at the development in other countries or just EU on a standalone basis?

  EUCalc reflection: the ambition levels are set at the country level. For some levers, if there are not enough reliable country-specific data or the differences among the countries are thought to be negligible, we assume them to be equal for all the European countries. This will be reported transparently in the background documentation and the improvements will be sought based on the scrutiny and feedback received during the upcoming EU Calc's Call for Evidence online consultation process.

- Expert input: do you incorporate possible (speculative) game changers (such as biomimetic composite materials, catalytic or biogenic hydrogen production, potential new storage materials for hydrogen or electricity) into the bill or do you deliberately leave it outside? If not you have to explain it (e.g. you do not expect these to be quantitative).

  EUCalc reflection: yes, novel technologies are incorporated, but only if we expect them to have a role in industry transition in the most transformational breakthrough scenario (level 4). They will also be considered in the module WP6, which will model the impact of policies.

3.3.2.1 Lever 1 - Material Switch

The main suggestions concerning the material switch lever and the associated ambition levels were:

- Expert input: what about plastic production as a possible "target industry" of material substitution? Probably too complicated and heterogeneous to depict in detail, but roughly, the balances between "giving" and "winning" industries should be visible.

  EUCalc reflection: the lever "material switch" considers only the most important switches that we expect to occur and that will impact the production of energy-intensive materials. Plastic production is not explicitly modelled, but it is included in the chemical industry. We are evaluating the costs and benefits of making a further split in this particular industry. In any case, the balance of these switches is taken into account in the model. E.g. the amount of steel replaced by carbon fiber in cars and trucks will correspond to a decrease in steel production and an increase in carbon fiber production (chemical industry).

- Expert input: in buildings, the percentage of substitution of concrete with advanced timber materials should be higher/more ambitious. For level 3 consider that there is no technological barrier for even 80% of all residential buildings under 12 stories to be built with wood by 2050. How do you account for the height of the building for the material substitution (relating to concrete to timber switch, and technological barriers for substitution as the height of buildings increases)? Also, how do you consider the other bio-based substitutes? Timber is a very restrictive definition, clarify if hemp, straw bale is included.

  EUCalc reflection: we took into account the opinion voiced and the level definition remains open until we collect further evidence to corroborate this. The building height is not considered explicitly in the model: we assume a switch from concrete to timber in a building of average height. However, we are evaluating to divide residential buildings into two height groups (to be discussed with the building module (WP2.1) module of the EUCalc) and applying different material switch percentages accordingly. In the switch from concrete to timber, we do not consider other bio-based substitutes. However, to account for the use of other bio-based materials in buildings we added a new material switch for the insulation surface where we model the substitution of chemicals with cellulose and natural fiber as hemp and straw bale.

- Expert input: the switch from concrete to insulation materials in buildings should be considered with care because concrete has a structural function.

  EUCalc reflection: we agree with this comment and have decided to remove this material switch. We will consider the use of natural fibers and cellulose for insulation in another specific material switch applied to the total insulated area.

- Expert input: do you include the increase in insulation material and glass when moving to low emissions buildings? For instance, improved insulation entails a transition from single glazing to double and triple glazing. Glass production emissions will change.

EUCalc reflection: we are considering the increase in insulation material used: the demand for insulation for residential and non-residential buildings is an input for our module coming from the building module (WP2.1). The glass production is currently not modelled in the manufacturing module since the glass industry in Europe is responsible for a minor share of greenhouse gas emissions compared with steel, cement, chemical and paper industries (see Fig.2). However, an increase of glass demand and the associated emissions will be accounted in the aggregated group of the 'other industries'.

- Expert input: the substitution rate from steel to carbon fiber in vehicles can probably be higher but there are many open questions. Material intensity of carbon fiber is lower but production emissions are higher per unit of material. Carbon fiber - carbon mixed with plastic - recycling technology is very expensive at the moment and if we increase switch towards carbon fiber how this is going to impact waste and recycling? Therefore, to justify the benefit of pushing towards carbon fiber, the full life cycle assessment of products e.g. cars should be evaluated such as life-span and intensity of use of cars in the future (electrified, transport as service - fewer vehicles used more intensively).

  EUCalc reflection: the lifetime and the intensity of use of cars are modelled in the transport module of EUCalc. We will evaluate if it is possible to use this information and link it with the material switch in cars.

- Expert input: the substitution rate from steel to aluminium in vehicles was considered low by some participants and higher percentages were suggested for consideration (40-50% for level 3).

  EUCalc reflection: to avoid possibly biased opinions we are looking for further references and identifying Expert Stakeholders to validate this assumption.

- Expert input: are the emissions due to a larger production of other materials accounted? Where is the resulting increase (e.g. chemicals, glass, ceramics, composite materials)?

  EUCalc reflection: yes, the increase in emissions in the production of other materials is accounted. Specifically, when the industry is modelled (e.g. chemicals) and on average when the industry is not explicitly modelled (e.g. glass, ceramics and composite materials are all included in the other industries group).

- Expert input: can concrete be substituted by non-chemical products? E.g. printing houses from waste or other new technologies/materials.

  EUCalc reflection: we will evaluate through a literature review if other material switches in buildings are going to be relevant in the future and then decide which to include.

- Expert input: with present practice/material use, the most important aspect of sustainability in cement production is a long lifetime of buildings and lifestyle choices e.g. how much space we need? Ceiling height is currently regulated (e.g. 2.30 m), but this may get reconsidered depending on future generation average tallness. Allegedly, ceiling height and room size will not impact the energy demand if the efficiency of the building envelope (by insulation) fulfills building regulation directives (e.g. European Building Performance Directive).

EUCalc reflection: lifetime of buildings is not accounted in the material intensity lever. This is considered in the building module (WP2.1) that calculates the demand for new buildings (residential and non-residential) and provides this information to the manufacturing module. This then assesses the amount of new materials needed to be produced in order to build them.

3.3.2.2 Lever 2 - Material Intensity

The main suggestions concerning the material intensity lever and the associated ambition levels were:

- Expert input: material intensity could be applied to each product instead to the materials. It would be better to have assumptions that are product specific to facilitate user understanding.

  EUCalc reflection: we will evaluate whether possible to apply the material intensity to each product instead of each material. However, applying the material intensity to each product implies a very large number of assumptions that could be difficult to validate with sound references. This is due to the long list of products (25), each of them composed of several materials. Our current intention is to apply it to the materials in order to have a more general approach that includes all the different drivers behind the material intensity.

- Expert input: material intensity values have been considered too conservative for cement by some participants. The level 4 should be 50% or more by 2050.

  EUCalc reflection: we take into account the concern and will collect further evidence in order to test this ambition level.

- Expert input: material intensity for steel was suggested as likely too high.

  EUCalc reflection: we are looking for further references to validate this input.

- Expert input: is it considered that lighter vehicles consume less fuel?

  EUCalc reflection: in the vehicle consumption lever of the transport module (WP2.2) of EUCalc it is considered that the fuel consumption in vehicles will decrease also due to their lighter weight (this decrease varies with the ambition level chosen).

- Expert input: what are the assumptions behind the material intensity lever? Do you include over-specification, manufacturing yields, and construction waste?

  EUCalc reflection: we prefer not to split this lever in order to limit the total number of levers of EUCalc. However, a documentation explaining the material intensity lever will list all the factors behind this lever, which can vary from material to material but generally speaking are:

    - *Use of better materials*
    - *Reuse of components*
    - *Smart design and light weighting*
    - *3D printing and digitalization*
    - *Reduction of overestimation*

3.3.2.3 Lever 3 - Technology Share/Recycling

The main Expert suggestions concerning the technology share/recycling lever and the associated ambition levels were:

- Expert input: concerning the share of the recycling route (scrap-EAF), the availability of corresponding scrap quantities and their quality are limiting factors. Especially the quality factor is important and for that, it is fundamental to have appropriate recycling processes and sorting stages.

  EUCalc reflection: we acknowledge that the availability of scrap and its quality is a limiting factor. For this reason, we consider that even in the more ambitious level the primary route (BF-BOF) will not be completely replaced by the recycling route (scrap-EAF).

- Expert input: how is on-site electricity generation considered? More and more industries are switching to on-site renewables.

  EUCalc reflection: this question is being discussed with the energy module (WP5). A possibility to include this point is to reduce the total electricity demand for high ambition levels (to consider that part of the electricity is already generated on site).

- Expert input: pace and shape of transformation are important. The pace is defining investments. For the shape, the number of technology suppliers for a given novel technology can be limiting (bottlenecks in production capacities for the novelty if demands grow quickly).

  EUCalc reflection: pace and shape of transformation are considered in the lever definition and not only for the deployment of novel technologies. To represent the pace of transformation, for each lever appropriate curves are chosen in order to model the evolution over time of the ambition level. These curves can be linear, exponential, logarithmic or S-shaped.

Specific comments on levels (in the framework of the current definition of levels):

- Expert input: the ambition levels of technology share in the steel industry seem realistic, however, the availability of good quality scrap can limit the spread of the recycling route. All technologies currently considered are already state-of-the-art and the only differences in the fuel mix may be expected.

  EUCalc reflection: we do not completely agree with the expert input as not all the technologies in the steel industry are at the highest level of development. E.g. Hisarna is a novel technology developed in the Ultra-Low Carbon Dioxide Steelmaking (ULCOS) project and at this moment only a pilot plant has been constructed, but we expect this technology to play a role in the most ambitious scenarios.

- Expert input: the ambition levels of technology share in the cement industry may be realistic, however, geopolymers can have a max share of 5-10% on a global level (not 20%) Roughly 5 technologies are linked to geopolymers they should be segmented (ref. IEA report).

  EUCalc reflection: we are looking for further references to validate this input. We are aware that there are several technologies linked to the *geopolymers, but also given the low share value, we prefer to keep them in one group.*

- Expert input: paper is not enough realistic, EU policy objective is 100% recycling already by 2030. Is demand for paper going to decrease? We may expect so. There is a large heat demand for pulp and paper, missing heat as an energy carrier.

  EUCalc reflection: we will look for other sources to validate the technology share of paper. We do expect the paper demand for printing and graphics to decrease and possibly the demand for paper packaging to increase. These demands will be provided to the manufacturing module by the lifestyle module. The heat will be added as an energy carrier.

- Expert input: re-thinking of levels to consider disruption:
  - level 4: disruptive transformation of the sector
  - level 3: Best available technologies (BAT) projections to 2050 (use EU sectorial roadmaps as references and IEA technology roadmaps which already went through Stakeholder consultation rounds)

  EUCalc reflection: levels 3 and 4 in our model are already reflecting this logic, level 3 is very ambitious but achievable and level 4 consider transformational breakthrough and disruption. It may be that the values chosen for some levers are not ambitious enough. Based on the Expert indications at the workshop and further literature review we will evaluate how to change them.

3.3.2.4 Lever 4 - Energy Carrier Mix

The main suggestions concerning the energy carrier mix lever and the associated ambition levels were:

- Expert input: level 4 is not ambitious enough. It was suggested to have 0% of fossil fuels for all the sectors, by increasing the hydrogen and electricity share (depending on the industry).

  EUCalc reflection: we will increase the share of hydrogen and electricity in level 4 in order to be more ambitious and we decided to keep for all industries the total share of fossil fuels between 0% and 10% in level 4 (not always 0% because it seems not realistic for some technologies even for level 4, like for example for steel primary route (BF-BOF)).

- Expert input: it is important to consider the limited availability of biomass. In certain industries, the use of biomass could be more required than in others (e.g. in the paper industry). They also point out that biomass is not CO_2 neutral.

  EUCalc reflection: the limited availability of biomass is considered by the agriculture module (WP4) of EUCalc, which estimates how much biomass is possible to grow in each country and how much can be imported. The CO_2 emissions associated with the biomass production are accounted for in agriculture module. If the demand of biomass by industry cannot be satisfied a warning will signal that in the pathways explorer.

- Expert input: heat should be added as an energy carrier. Waste heat and heat integration are important aspects in many industries.

EUCalc reflection: the heat carrier is being added to the energy carrier mix.

- Expert input: specific comments on the energy carrier mix:
  - Steel DRI-EAF (direct reduced iron - electric arc furnace) - level 4 it was suggested that it should be 50% Hydrogen, 50% Gas
  - Steel BF-BOF(blast furnace-basic oxygen furnace)– in level 4 it was suggested that the share of biomass too large, it could be 15%.
  - Cement dry-kilns – in level 4 it was suggested that the share of biomass is too large and the share of waste too low.

  EUCalc reflection: to take into account possibly different schools of thought and have unbiased ambition levels we will look for further references before possibly modify these ambition levels.

3.3.2.5 Lever 5 - Technology Development

The main suggestions concerning technology development and the associated ambition levels were:

- Expert input: some new technologies could require more energy. For example, the use of hydrogen for steel production.

  EUCalc reflection: we will think about how to include that in our model.

- Expert input: flexibility in changing the energy demand of the industry is important to cover the peak of electricity in the power sector.

  EUCalc reflection: this issue will be discussed with the energy module (WP5).

- Expert input: specific comments on levels of ambitions:
  - for level 4 of technology development of the technology scrap-EAF (electric arc furnace) for the steel production it was suggested that there should be a max of 4% of the increase in energy efficiency.
  - level 1of technology development of dry-kilns in cement production is correct, but it was suggested that other levels are too ambitious.
  - regarding the technology development in the chemical industry, it was suggested to check the values with the DECHEMA report for energy efficiency (e.g. increase of 0.56% a year for level 1-2).

  EUCalc *reflection: we will take into account these comments and check them with a further literature review. We will also counter check with the DECHEMA report to determine if our ambition levels are indeed correct.*

3.3.2.6 Lever 6 - Carbon Capture and Storage

The main suggestions concerning the CCS lever and the associated ambition levels were:

- Expert input: in addition to CCS, CCU (Carbon Capture and Use) should be considered. In the medium term, this will provide secondary carbon or even direct CO_2, e.g. as a raw material in the chemical industry (even the very conservative German chemical industry is considering this approach).

In the long term, it can even form a CO_2 sink if the emissions of biomass incineration are reused.

EUCalc reflection: we will do further research on the topic and evaluate if and how to include it. Additionally, a joint technology development workshop of the three projects, EU Calculator, INNOPATHS and REINVENT is planned early 2019, also in order to assess costs and values.

- Expert input: for CCS, it is necessary to justify why it is used in certain industries (ammonia, cement, possibly steel and waste incineration), but presumably excludes coal for power generation. Regarding the later, there could be controversial discussions, for example, in the case of Poland.

  EUCalc reflection: CCS in power generation is covered by the energy module of EUCalc, which will assess realistic ambition levels for each European country.

- Expert input: CCS is currently forbidden in some European countries (e.g. Austria). How do you consider that?

  EUCalc reflection: even if now it is forbidden, this could change in the future years. For this reason, we have decided to leave open the possibility to have CCS deployment also in these countries. If the law will not change it is possible to account for that by just choosing the level 1 for CCS which considers no deployment at all of this technology.

- Expert input: the realistic share of emissions that could be captured with CCS in the cement industry was suggested to be 30%. Beyond that gets into political and infrastructure constraints.

  EUCalc reflection: we will look for further references to validate this concern raised by the Stakeholders.

- Expert input: if in the energy mix there are no fossil fuels or biomass there will be not CO_2 left that needs to be captured (no need of CCS).

  EUCalc reflection: yes, exactly, however in no scenario for the industries modelled the share of biomass and fossil fuels is 0%. Even if there was such a case the model will see this inconsistency and not apply the CCS and possibly create a warning.

- Expert input: Companies like Statoil and Gazprom are evaluating this possibility of using CCS to convert gas into H_2 and ship H_2 using the same infrastructure currently used for gas.

  EUCalc reflection: we will do further research on this topic, however, the hydrogen production and distribution are modelled by the energy module (WP5) of EUCalc.

4 Lessons and conclusions

The Expert consultation was a very important step for the development of the manufacturing module of EUCalc. The set of Experts invited covered a wide range of expertise: members of industrial associations (steel, cement, paper, chemicals), researchers in the field of economics, members of energy agencies as well as renowned policy think tanks.

Both in the general discussion following the presentation of our assumptions and in the smaller discussion groups we were able to collect a significant number of suggestions and observations ranging from the general scope of the manufacturing module to the specific ambition levels of the levers.

The comments and critical suggestions provided by participants at the event were considered in the light of available evidence and were answered in a transparent way in this report. After the consultation, changes in the module (level of ambition) were made according to a) Experts feedback and b) further literature review. Major changes in the ambition of levels resulted in:

- Increase of the ambition levels of the material switch lever – steel replaced by aluminium in cars and trucks (Luk J. M. et al.,2018; Ducker Worldwide, 2017)
- Increase of the ambition levels of the material switch lever– concrete replaced by timber in buildings (Gustavsson L. and Sathre R., 2011; Sathrea R. and O'Connorb J., 2010; Werner F. et al., 2005)
- Increase of hydrogen share in the energy carrier mix lever of steel DRI-EAF (direct reduced iron - electric arc furnace)(Eurofer, 2013; Energy Transition Commission, Steel, 2018)
- Increase of hydrogen share in the energy carrier mix lever of ammonia production (DECHEMA, 2017)
- Increase of the ambition levels of the technology development lever - energy efficiency of chemicals(DECHEMA, 2017)
- Decrease of the ambition level of CCS for steel primary route (BF-BOF) and cement (European Cement Research Academy, 2017; Cembureau, 2013; Eurofer, 2013; IEA, 2016)

The validated ambition levels are shown in Annex 6.3.

Following the input of the Expert Stakeholders, two new material switches have been added to the model and one removed:

- Chemicals replaced by natural fibers in renovated surfaces (added)
- Chemicals replaced by cellulose (paper) in renovated surfaces (added)
- Concrete replaced by chemicals (removed)

The feedback concerning greater granularity in resolution (addition of more industrial sectors, energy carriers, and technologies) will be considered and discussed with the involved modules (e.g. energy module for the energy carriers) for the next versions of the model.

Where offered, additional reviews of specific levers will be carried out by Experts who could not take part in the workshop in the public call for evidence.

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6 Annexes

6.1 Participants list

Participants – Stakeholders:

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Mariësse	van Sluisveld	Planbureau voor de Leefomgeving (PBL) - Netherlands Environmental Assessment Agency
Tadeusz	Skoczkowski	Warsaw University of Technology
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Facilitator:

First Name	Last Name	Organisation
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6.2 Workshop agenda

Date

Tuesday, July 10th 2018, from 10.30 to 14.30 CET

Venue

Haus der Industrie, Spiegelsaal

Schwarzenbergplatz 4,1030 Vienna

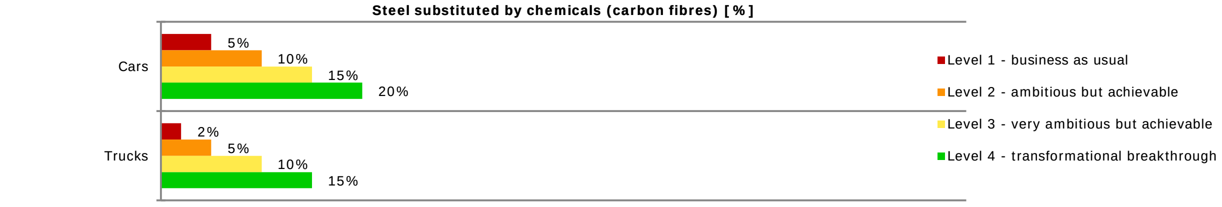
Agenda

10:00	Registration and coffee
10:30	**Opening**& Welcome Hannes Warmuth, ÖGUT Jonathan Buhl, Facilitator, 4sing
10:45	**Introducing the European Calculator**, followed by Q&A Judit Kockat, BPIE
11:00	**Keynote**: Rethinking the European Industry Märtha Rehnberg; Co-Founder & Partner DareDisrupt
11:25	**Insights Q&A** from Horizon 2020 sister projects Tadeusz Skoczkowski, Warsaw University, INNOPATHS Mariësse van Sluisveld, PBL Netherlands Environmental Assessment Agency, REINVENT
11:40	Coffee & Tea break
12:00	**Introducing the manufacturing and production module** Hannes Warmuth, Stefania Tron, ÖGUT
12:30	**Interactive dialogue** (facilitated breakout sessions)
13:50	**Recap and overview** (actions and next steps)
14:00	Lunch (catered)
14:30	Workshop close

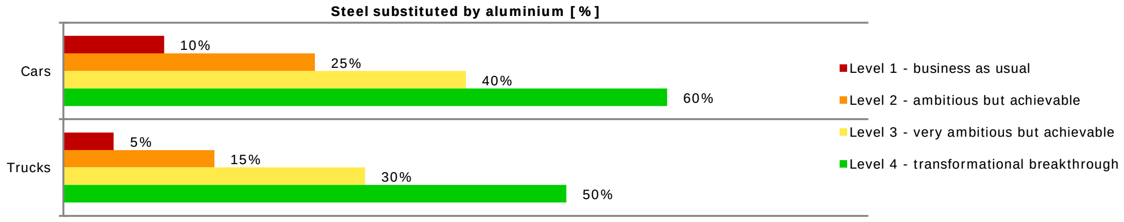
6.3 Ambition levels of levers of the manufacturing and production module

LEVER 1 – MATERIAL SWITCH

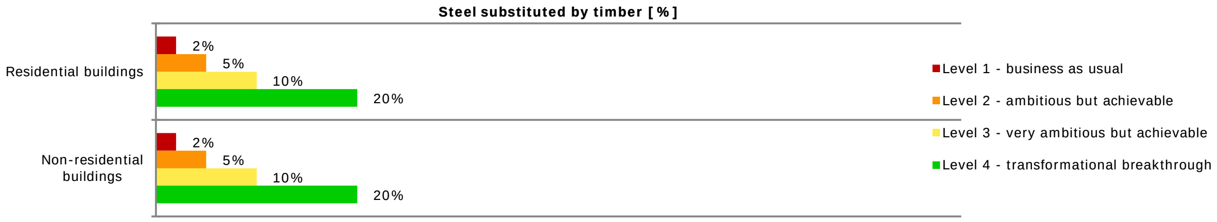
With this lever we want to quantify the main material switches occurring in products (e.g. in cars, buildings, etc.). It is expressed as the percentage of material in a product that is expected to be substituted by 2050 by a less carbon-intensive material. To keep the model as simple as possible we have chosen to represent only the most relevant material substitutions, i.e. those that are expected to have a larger impact on the material production.



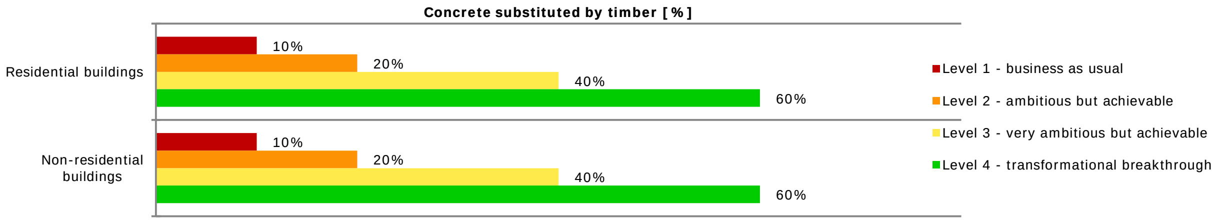
Steel substituted by chemicals (carbon fibres) [%]
Cars
5%
10%
15%
20%
Trucks
2%
5%
10%
15%
Level 1 - business as usual
Level 2 - ambitious but achievable
Level 3 - very ambitious but achievable
Level 4 - transformational breakthrough



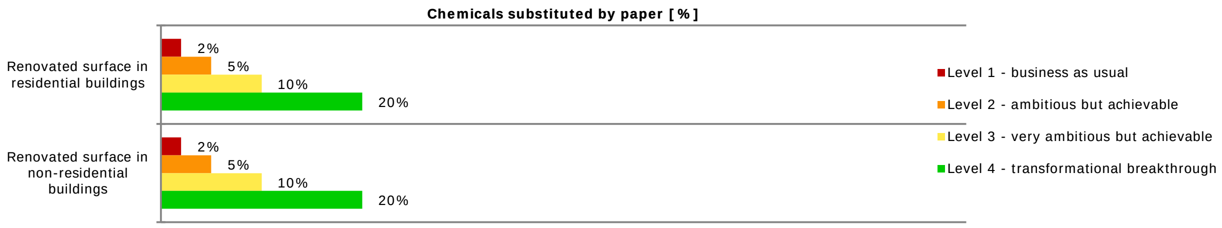
Steel substituted by aluminium [%]
Cars
10%
25%
40%
60%
Trucks
5%
15%
30%
50%
Level 1 - business as usual
Level 2 - ambitious but achievable
Level 3 - very ambitious but achievable
Level 4 - transformational breakthrough



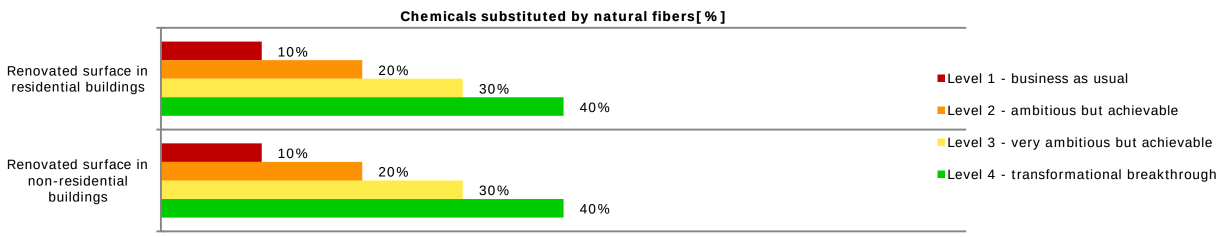
Steel substituted by timber [%]
Residential buildings
2%
5%
10%
20%
Non-residential buildings
2%
5%
10%
20%
Level 1 - business as usual
Level 2 - ambitious but achievable
Level 3 - very ambitious but achievable
Level 4 - transformational breakthrough



Concrete substituted by timber [%]
Residential buildings
10%
20%
40%
60%
Non-residential buildings
10%
20%
40%
60%
Level 1 - business as usual
Level 2 - ambitious but achievable
Level 3 - very ambitious but achievable
Level 4 - transformational breakthrough



Chemicals substituted by paper [%]
Renovated surface in residential buildings
2%
5%
10%
20%
Renovated surface in non-residential buildings
2%
5%
10%
20%
Level 1 - business as usual
Level 2 - ambitious but achievable
Level 3 - very ambitious but achievable
Level 4 - transformational breakthrough



Chemicals substituted by natural fibers[%]
Renovated surface in residential buildings
10%
20%
30%
40%
Renovated surface in non-residential buildings
10%
20%
30%
40%
Level 1 - business as usual
Level 2 - ambitious but achievable
Level 3 - very ambitious but achievable
Level 4 - transformational breakthrough

Sources:

Expert consultation

Luk J. M. et al. (2018), Greenhouse gas emission benefits of vehicle lightweighting: Monte Carlo probabalistic analysis of the multi material lightweight vehicle glider. Transportation Research Part D. 62, 1–10

Ducker Worldwide (2017), Aluminum content in North American light vehicles 2016 to 2028

NHSTA (2012), Mass Reduction for Light-Duty Vehicles for Model Years 2017-2025

Worldsteel Association (2016), Fact Sheet - Advanced steel applications

Gustavsson L. and Sathre R. (2011), Energy and CO2 analysis of wood substitution in construction. Climatic Change 105 – 129

Sathrea R. and O'Connorb J. (2010), Meta-analysis of greenhouse gas displacement factors of wood product substitution, Environmental Science & Policy, 13, 2, 104-114

Werner F. et al. (2005), Carbon pool and substitution effects of an increased use of wood in buildings in Switzerland: first estimates. Annals of Forest Science, 62 (8), 889-902.

LEVER 2 – MATERIAL INTENSITY

This lever represents the percentage of decrease of material use in products due to a number of factors, which are listed hereafter for each material considered.

Steel

- Use of high strength steel – It enable to reduce the use of steel in products and provide the same service
- Reuse – Many steel components could be reused without re-melting them with a better organized supply chain
- Smart design and light weighting – Often products are designed and built with more steel than would be required to provide the required function and to meet the necessary safety specifications. Smart design would reduce steel use without compromising functionality and safety
- 3D printing and digitalization – A digitalized production can improve the material efficiency
- Reduction of yield losses – Improvement of semi-manufacturing and manufacturing yields

Cement

- Reuse – Modular design of building components can enable the reuse of building components. Hardened cement cannot be recycled for reuse, however concrete can be crushed and used as aggregate to create new concrete.
- Reduction of overestimation – Buildings and infrastructures are in some cases designed and built with more cement than would be required to provide the required function and to meet the necessary safety

specifications. Overestimation reduction allows to reduce cement use without compromising functionality and safety

- 3D printing and digitalization – A digitalized production with the use of 3D printing can optimize the material use
- Appropriate exposure class for concrete – Concrete which is not exposed outdoor requires a lower cement content because is not exposed to environmental stressors like freeze-thaw conditions, water etc. However in some cases buildings are by default built with the highest exposure class increasing the cement demand.
- (Clinker to cement ratio reduction)

Ammonia

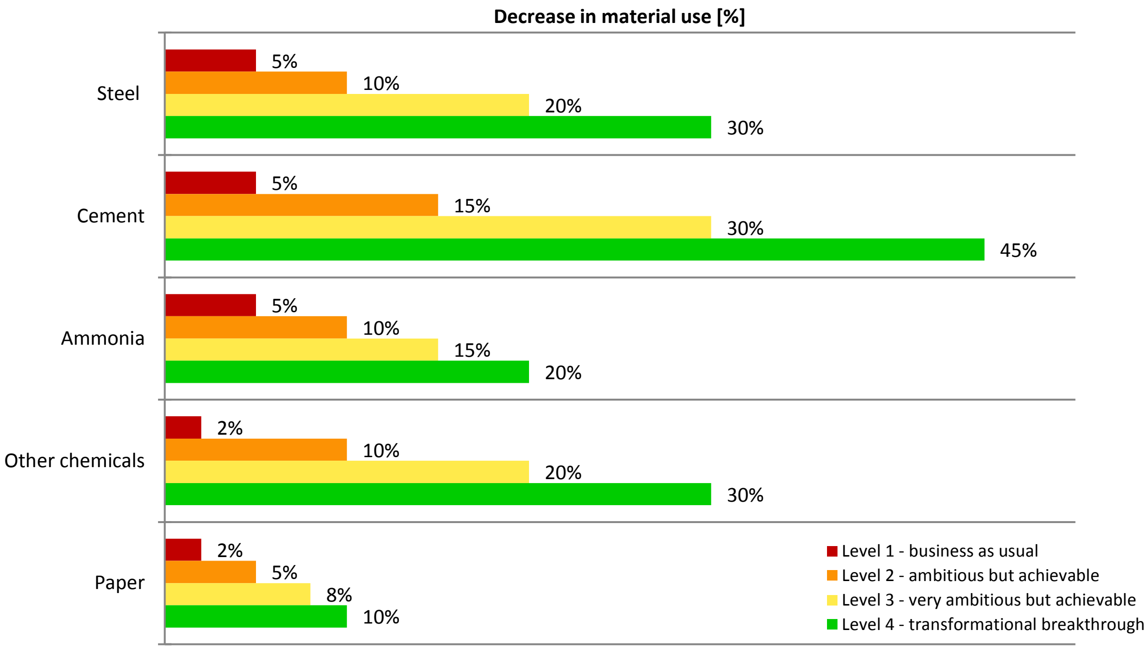
- Improvement of nitrogen fertilizer efficiency – Use the correct amount of fertilizers only in the required location to meet the nutrient demand of the crops and avoid losses

Other chemicals

- Smart design - Using design strategies to reduce the use of material for the same service, e.g. lighter plastic bottles or less detergent for the same level of cleanliness
- 3D printing and digitalization – A digitalized production with the use of 3D printing can optimize the use of plastic
- Reuse – Reuse of plastic consumer goods like bottles or packaging

Paper

- Smart design – Use less dense paper



Sources:

Expert consultation

Material economics (2018), The circular economy – A powerful force for climate mitigation

Alwood J. M. et al. (2010), Options for achieving a 50% cut in industrial carbon emissions by 2050. Environ. Sci. Technol. 44, 1888–1894

Alwood J. M. et al. (2011), Material efficiency: A white paper, Resources. Conservation and Recycling, 55, 362–381

Worrell E, Meuleman B, Blok K. (1995) Energy savings by efficient application of fertilizer. Resources, Conservation and Recycling, 13, 233–50

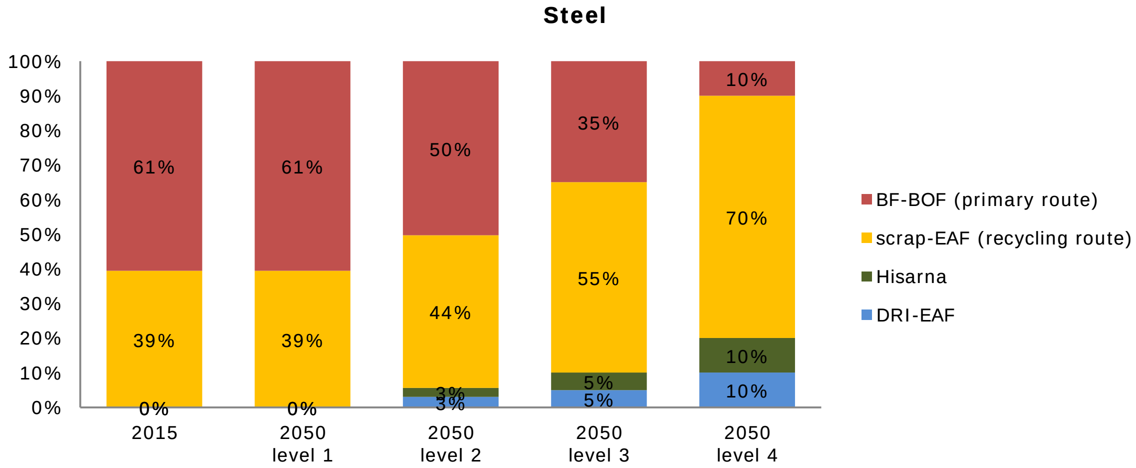
Cooper D. R. and Allwood J. M. (2012), Reusing steel and aluminium components at end of product life, Environ. Sci. Technol. 46, 10334-10340

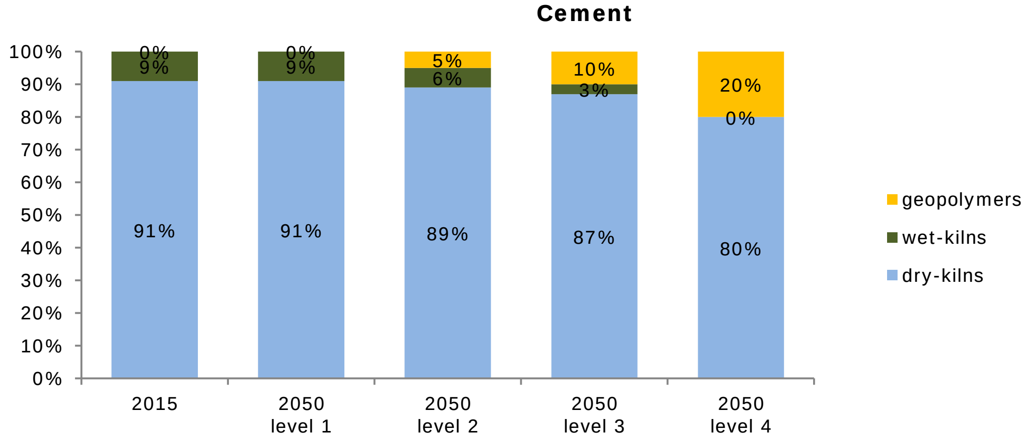
Milford R. L. et al. (2013), The Roles of Energy and Material Efficiency in Meeting Steel Industry CO2 Targets. Environ. Sci. Technol. 47 (7), 3455–3462

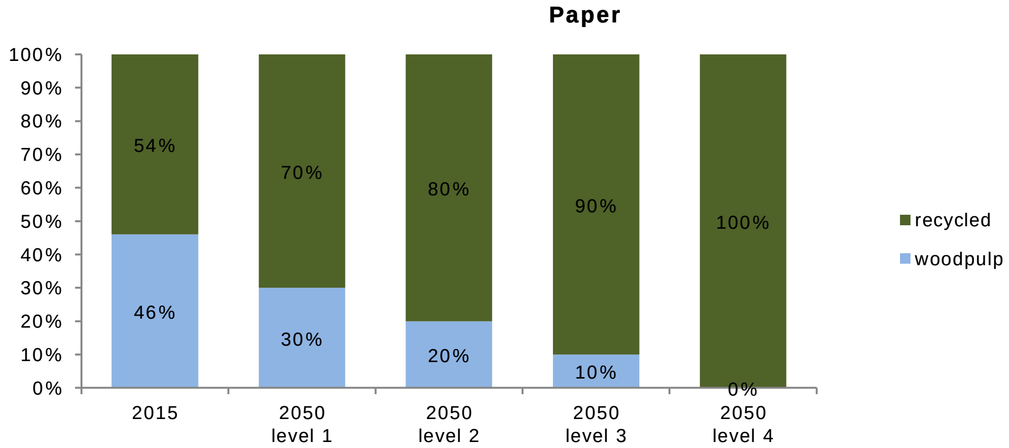
Huuhka et al. (2015), Reusing concrete panels from buildings for building: Potential in Finnish 1970s mass housing, Resources, Conservation and Recycling, 101, 105-121

LEVER 3 – TECHNOLOGY SHARE / RECYCLING

This lever describes the percentage of material produced with a given technology in each industry. In this lever we consider the deployment of new emerging technologies as well as the share of recycled materials.







Sources:

Expert consultation

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BCG and VDEh (2013), Steel‘s contribution to a low-carbon Europe 2050

Tata Steel (2018), Hisarna: game changer in the steel industry

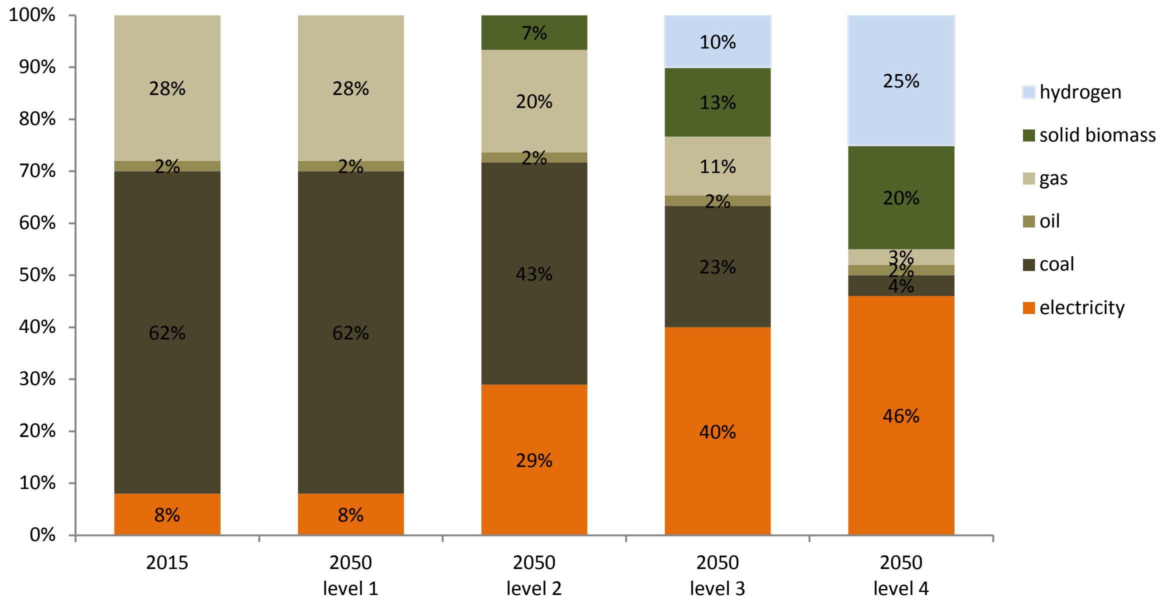
Eurofer (2013), A steel roadmap for a low carbon Europe 2050

CEPI, Investing in Europe for Industry Transformation, 2050 Roadmap to a low-carbon bioeconomy

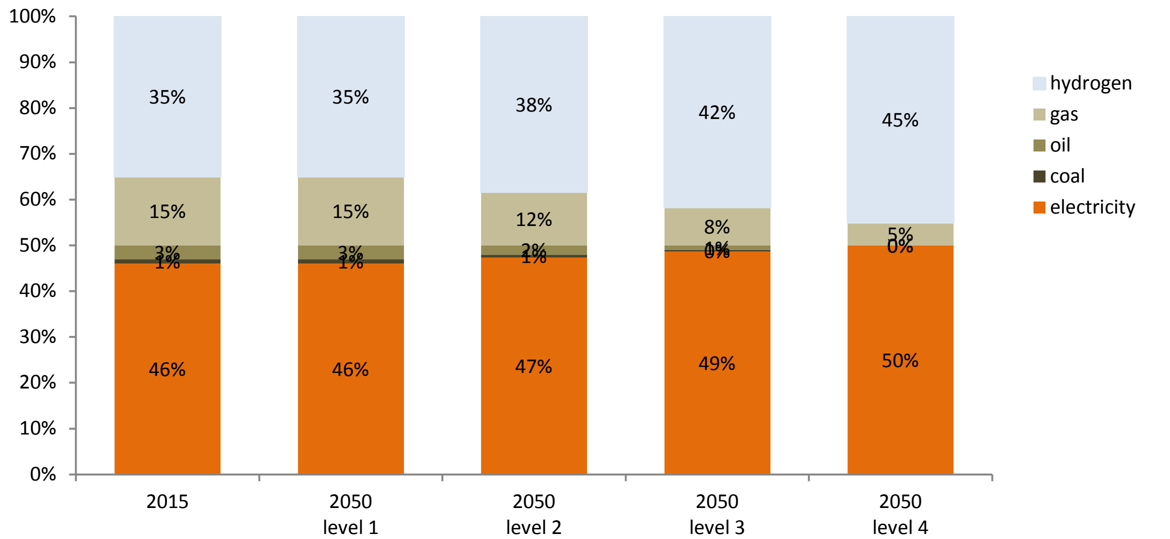
LEVER 4 – ENERGY CARRIER MIX

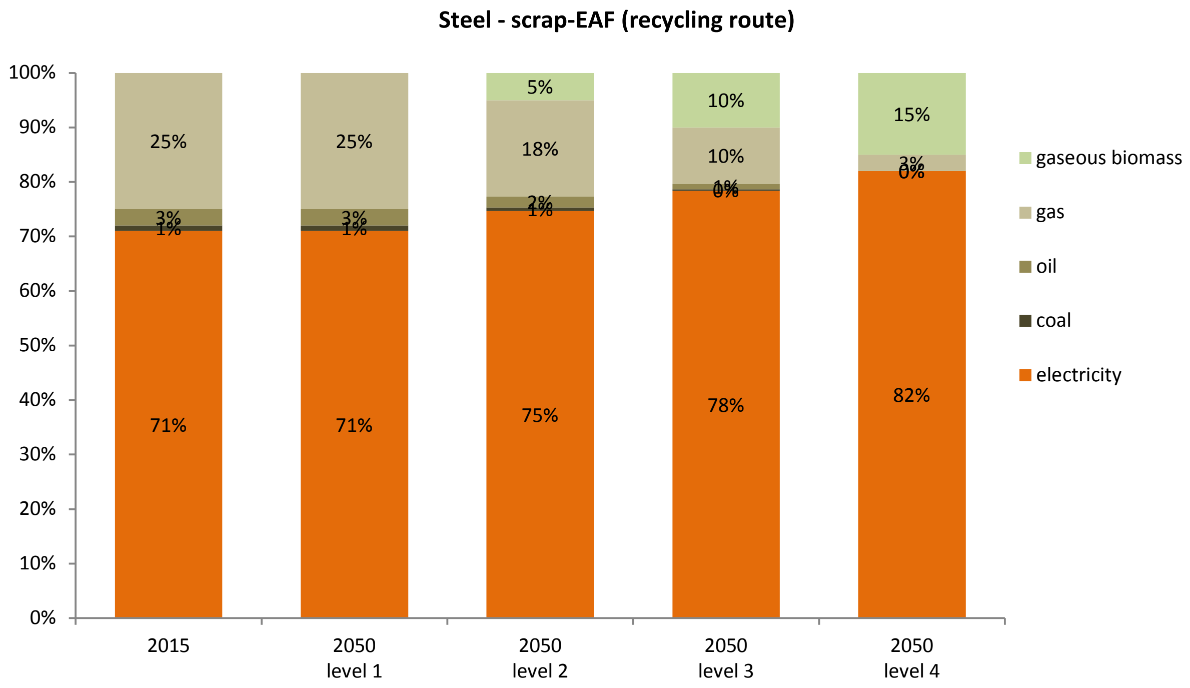
This lever assesses for each industry and each technology the energy carrier mix (which includes both feedstocks and energy) and how it is going to change by 2050. The energy carrier mix includes electricity, coal, oil, gas, solid biomass, liquid biomass, gaseous biomass, waste, and hydrogen.

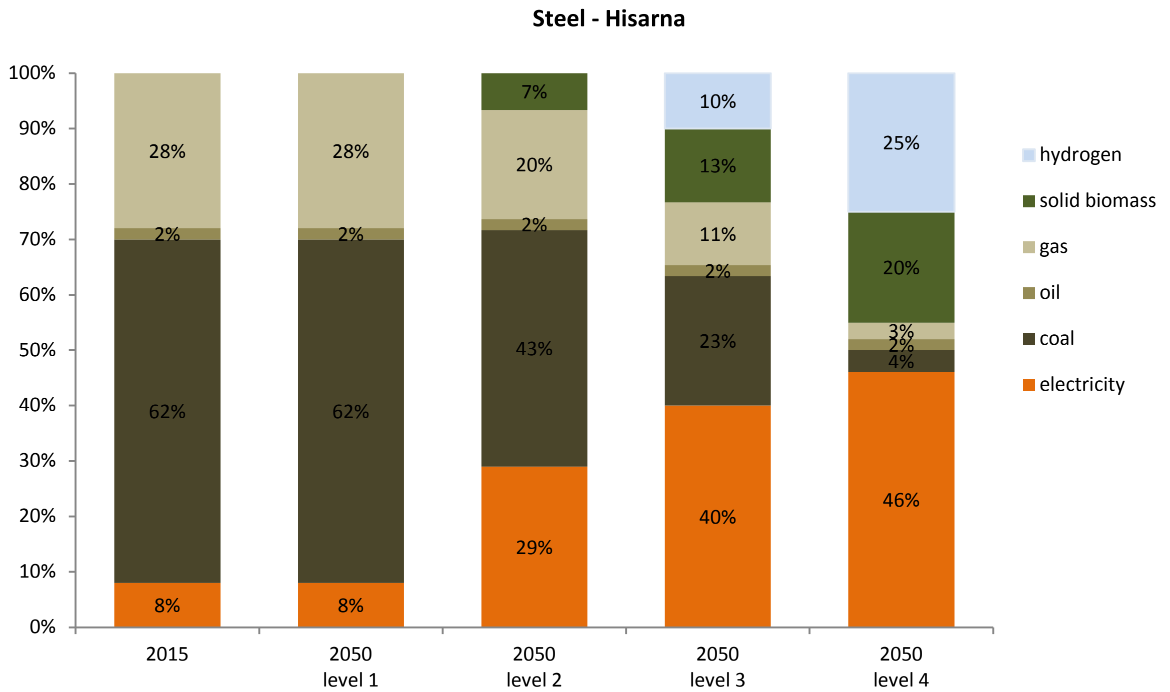
Steel - BF-BOF (primary route)



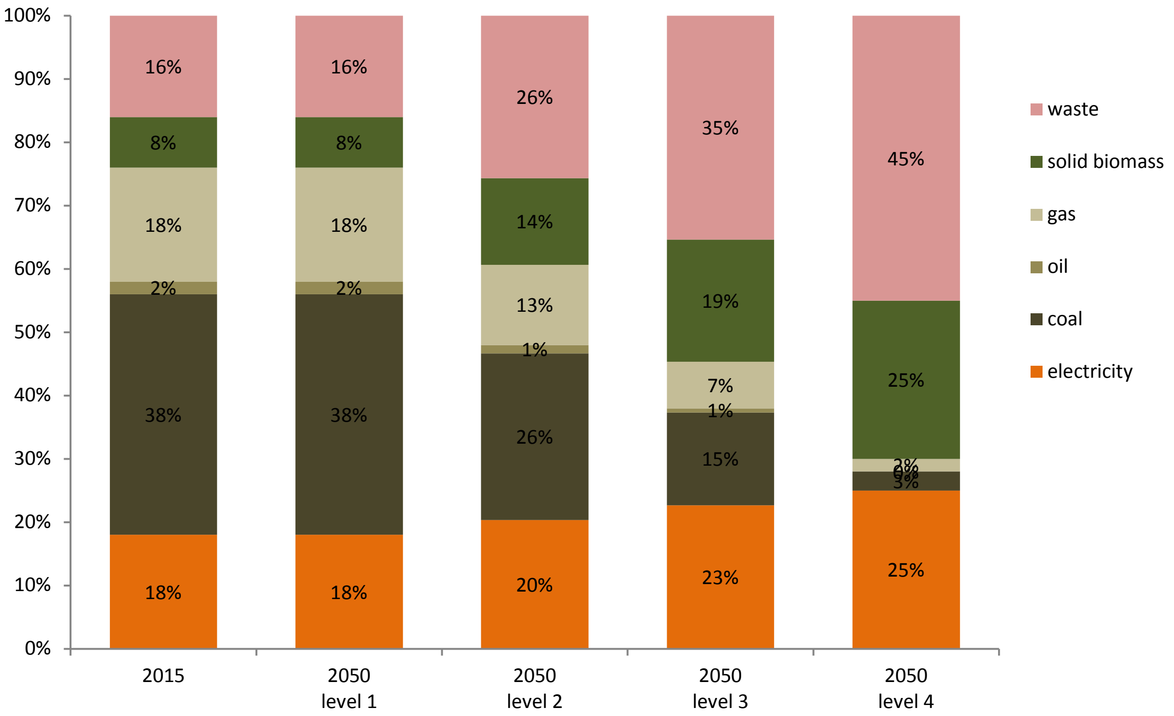
Steel - Hydrogen-DRI



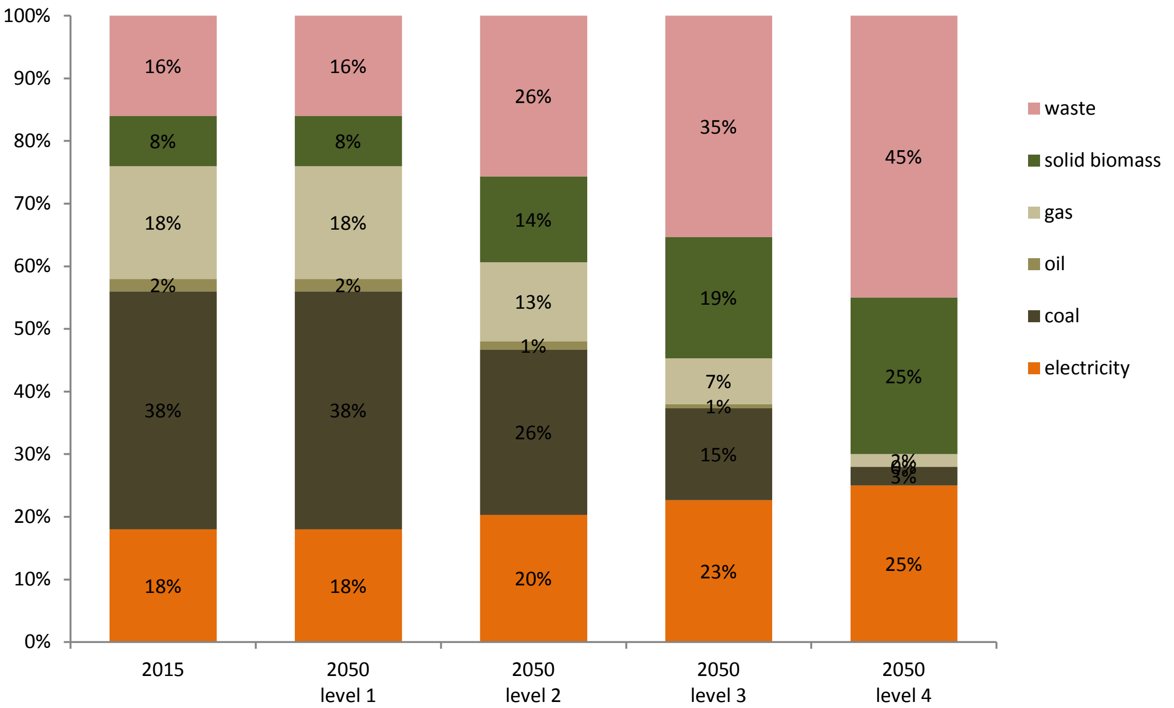

Steel - scrap-EAF (recycling route)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
25%
3%
1%
71%
5%
18%
2%
75%
10%
10%
1%
0%
78%
15%
3%
0%
82%
2015
2050 level 1
2050 level 2
2050 level 3
2050 level 4
gaseous biomass
gas
oil
coal
electricity


Steel - Hisarna
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
28%
2%
62%
8%
7%
20%
2%
43%
29%
10%
13%
11%
2%
23%
40%
25%
20%
3%
2%
4%
46%
2015
2050 level 1
2050 level 2
2050 level 3
2050 level 4
hydrogen
solid biomass
gas
oil
coal
electricity

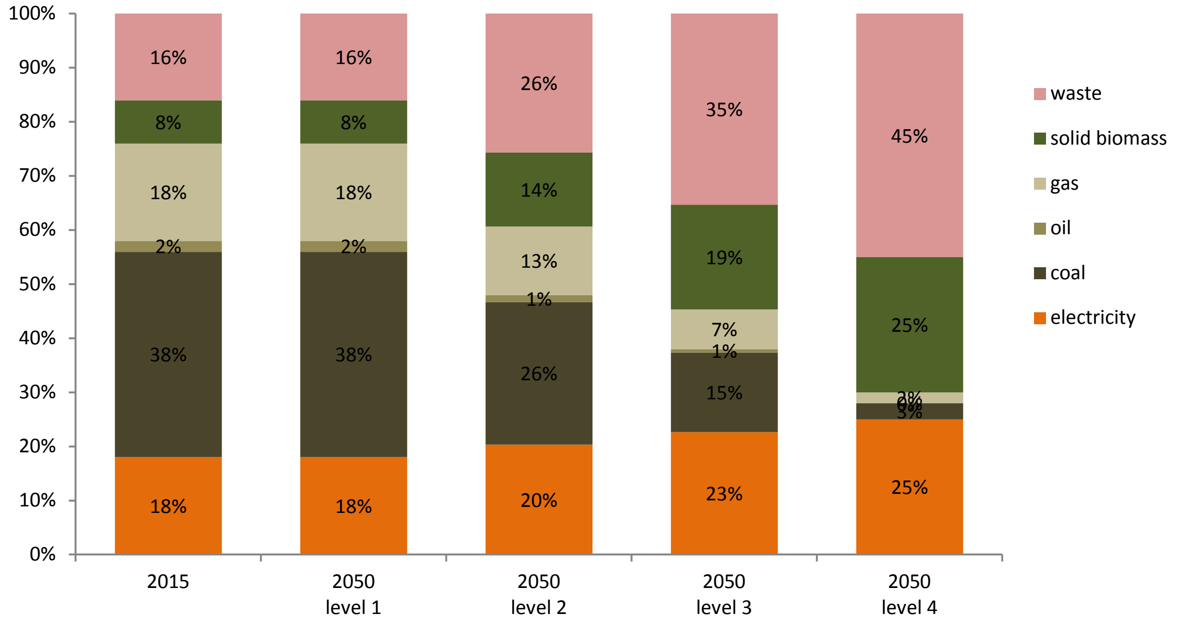
Cement - dry-kilns



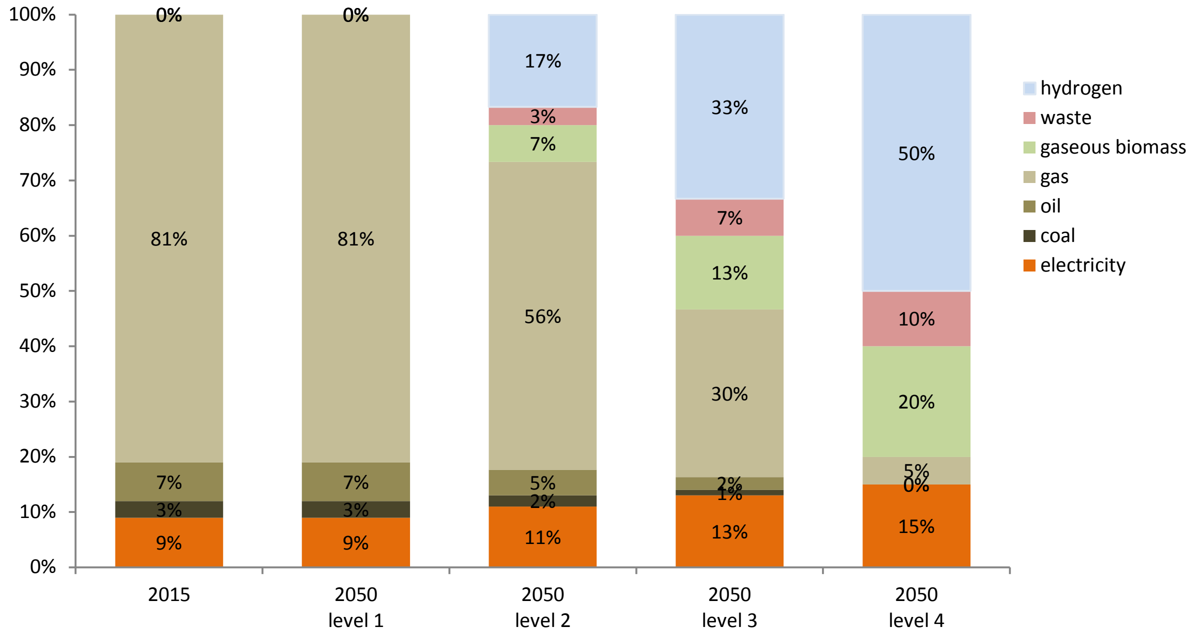
Cement - wet-kilns

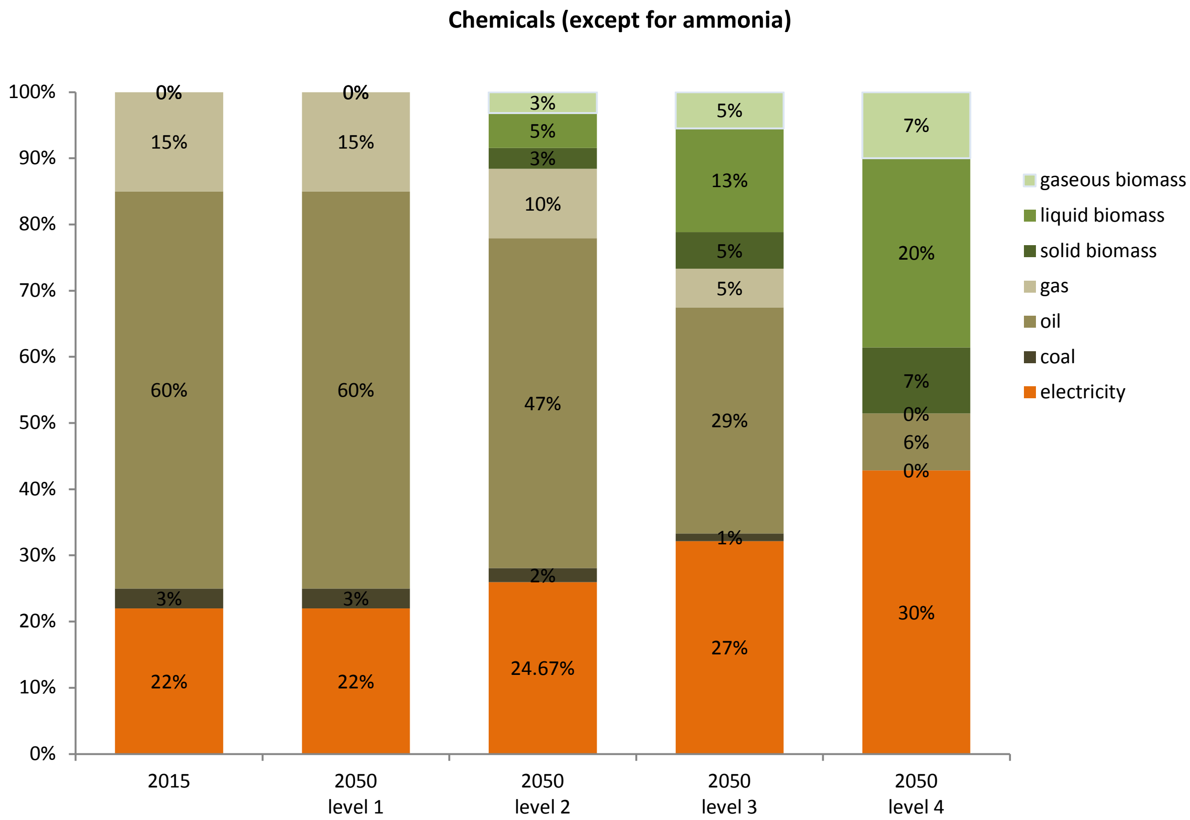


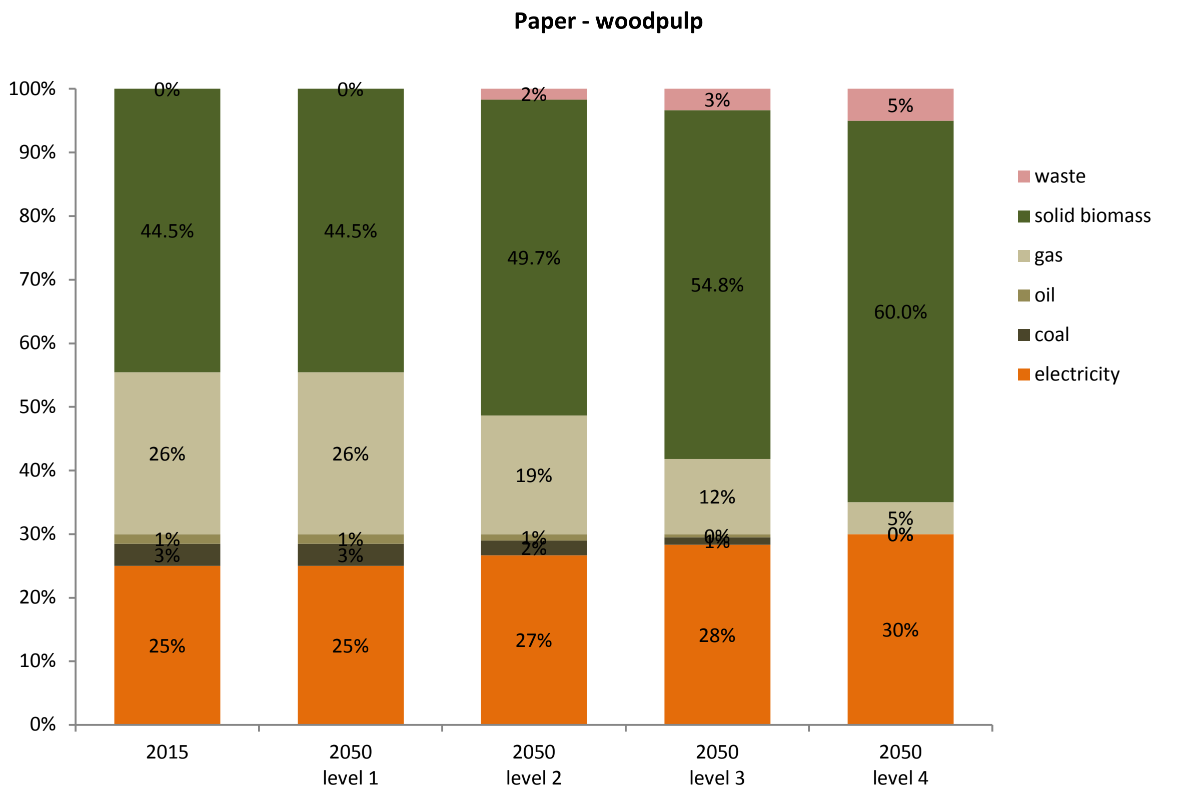
Cement - geopolymers

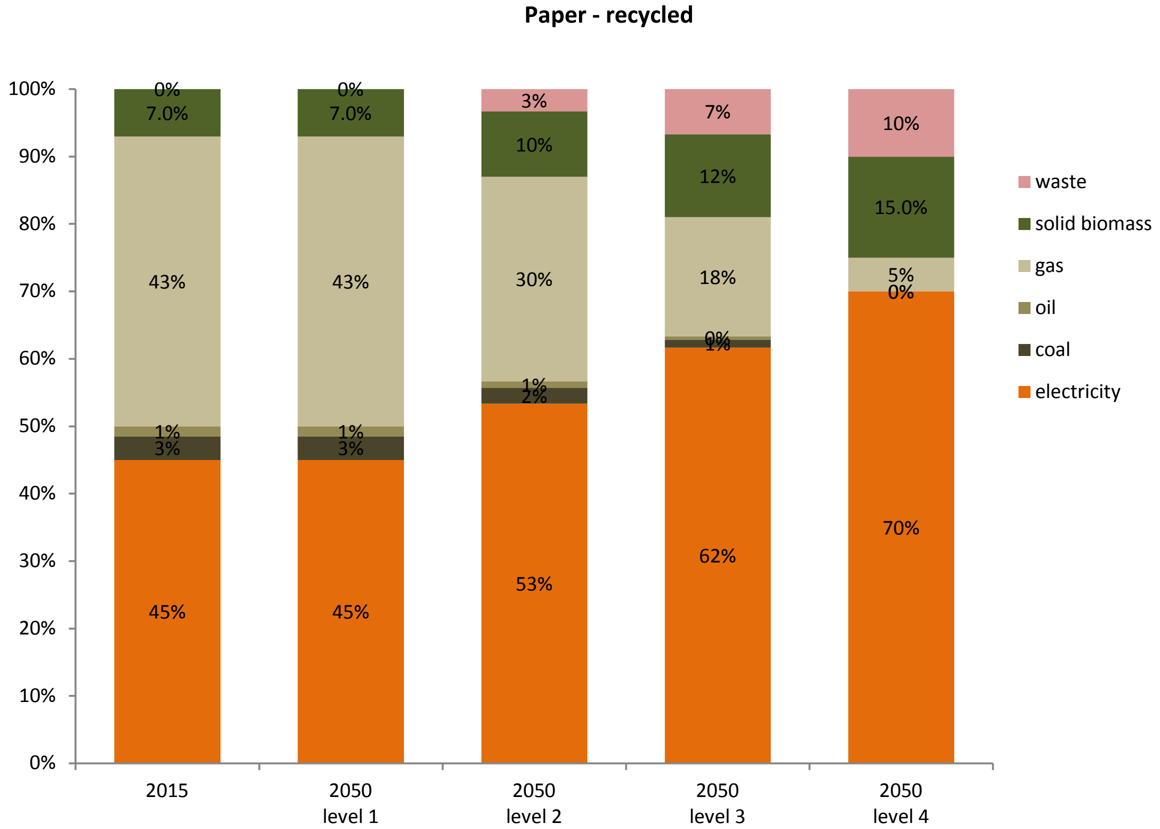


Ammonia




Chemicals (except for ammonia)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0%
15%
60%
3%
22%
0%
15%
60%
3%
22%
3%
5%
3%
10%
47%
2%
24.67%
5%
13%
5%
5%
29%
1%
27%
7%
20%
7%
0%
6%
0%
30%
2015
2050 level 1
2050 level 2
2050 level 3
2050 level 4
gaseous biomass
liquid biomass
solid biomass
gas
oil
coal
electricity


Paper - woodpulp
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0%
44.5%
26%
1%
3%
25%
0%
44.5%
26%
1%
3%
25%
2%
49.7%
19%
1%
2%
27%
3%
54.8%
12%
0%
1%
28%
5%
60.0%
5%
0%
30%
2015
2050 level 1
2050 level 2
2050 level 3
2050 level 4
waste
solid biomass
gas
oil
coal
electricity



Sources:

Expert consultation

Mariësse van Sluisveld et al. (2018), EU decarbonisation scenarios for industry, Deliverable 4.2, REINVENT – PROJECT NR 730053 (p.38)

BCG and Prognos (2018), Klimapfade für Deutschland

ICF (2015), Study on energy efficiency and energy saving potential in industry and on possible policy mechanisms

Worldsteel Association (2016), Fact Sheet - Addressing climate change through technology transfer and research

Arens et al. (2012), Energy intensity development of the German iron and steel industry between 1991 and 2007. Energy; 45:786–97.

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Cembureau (2013), The role of CEMENT in the 2050 LOW CARBON ECONOMY

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Gilbert et al (2014) Assessing economically viable carbon reductions for the production of ammonia from biomass gasification. Journal of Cleaner Production 64 581-589

EFMA (2000), Best Available Techniques for Pollution Prevention and Control in the European Fertilizer Industry. In: Booklet No.1: Production of Ammonia. European Fertilizer Manufacturers Association, Brussels.

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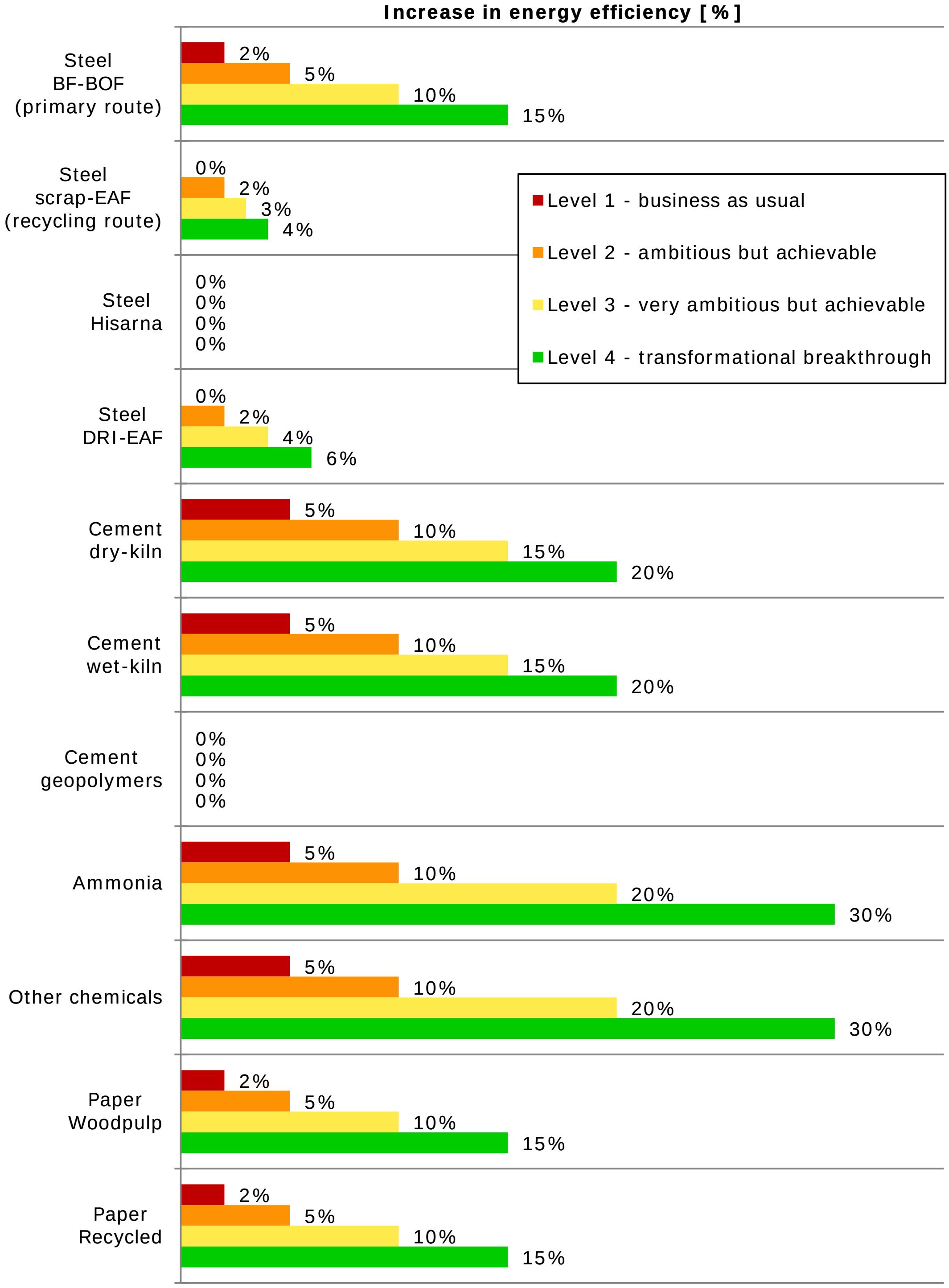
Griffin et al. (2018), Industrial decarbonisation of the pulp and paper sector: A UK perspective. Applied Thermal Engineering. 134 152-162 fig.8

Roth S et al. (2016), The pulp and paper overview paper, Sector analysis for the Climate Strategies Project on Inclusion of Consumption in Carbon Pricing. Climate Strategies tab.8

DECHEMA (2017), Low carbon energy and feedstock for the European chemical industry p-148-156

LEVER 5 – TECHNOLOGY DEVELOPMENT

With this lever we want to quantify the increase of energy efficiency in the technologies used to produce steel, cement, chemicals, and paper. The percentage reflects the decrease in energy consumption by 2050 due to energy efficiency measures.



Sources:

Expert consultation

Mariësse van Sluisveld et al. (2018), EU decarbonisation scenarios for industry, Deliverable 4.2, REINVENT – PROJECT NR 730053 (fig.25 and fig.44)

ICF (2015), Study on energy efficiency and energy saving potential in industry and on possible policy mechanisms

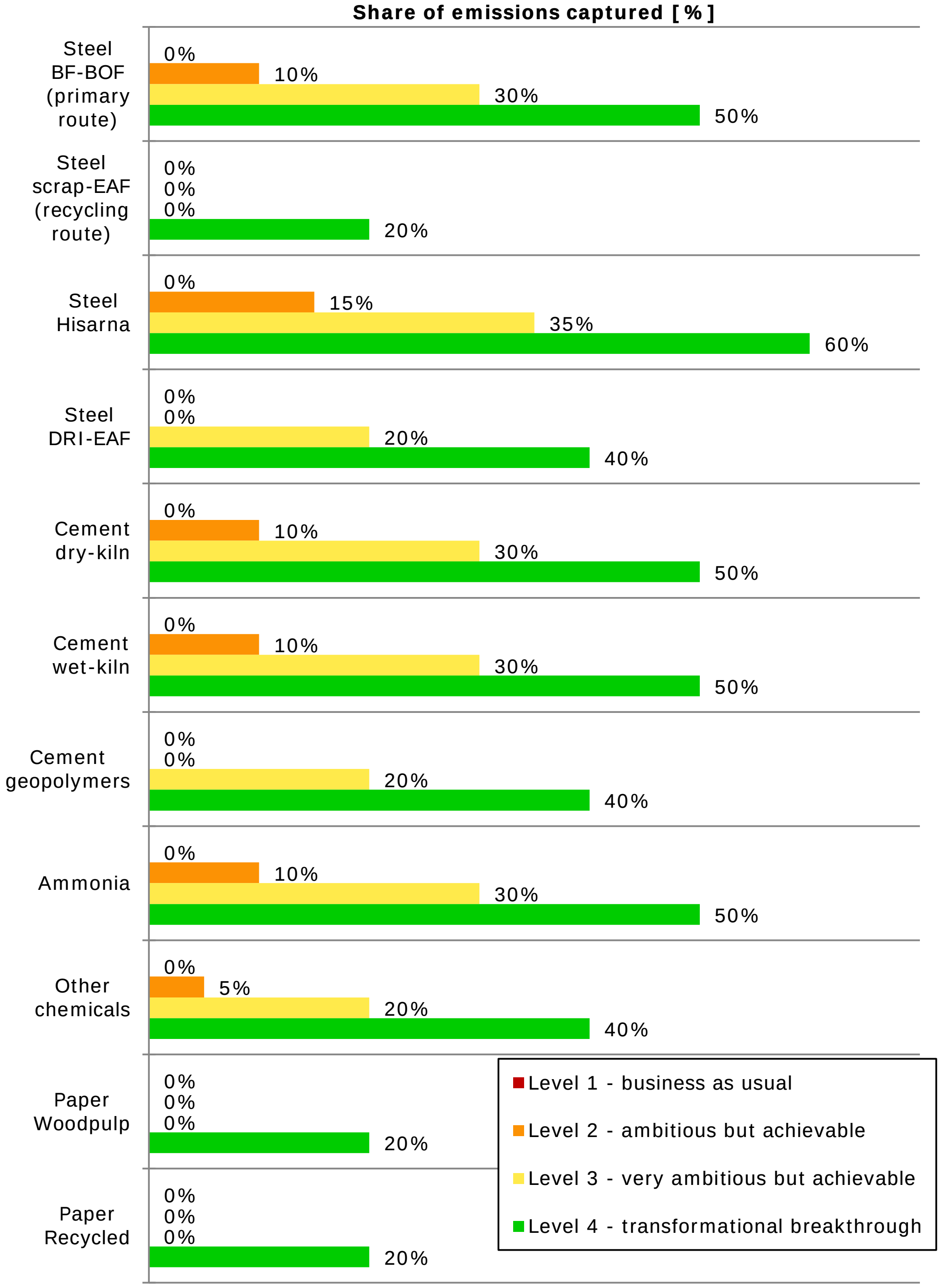
CEPI, Investing in Europe for Industry Transformation, 2050 Roadmap to a low-carbon bioeconomy

JRC (2013), Technology Map of the European Strategic Energy Technology Plan

DECHEMA (2017), Low carbon energy and feedstock for the European chemical industry p-148-156

LEVER 6 – CARBON CAPTURE AND STORAGE

This lever shows the deployment of CCS by 2050 in industry. The percentage represents the C02 equivalent emissions captured with CCS in each industry.



Sources:

Expert consultation

BCG and VDEh. 2013. Steel's Contribution to a Low-Carbon Europe 2050

European Cement Research Academy (2017), Technology Papers, Development of State of the Art Techniques in Cement Manufacturing: Trying to Look Ahead p.29

Cembureau (2013), The role of CEMENT in the 2050 LOW CARBON ECONOMY p.45

Eurofer (2013), A steel roadmap for a low carbon Europe 2050

Easac (2013), Carbon capture and storage in Europe

IEA, Technology Roadmap Carbon Capture and Storage

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