REINVENT – PROJECT NR 730053

Drivers of low-carbon innovation

Deliverable 3.6

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2019-10-31

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Executive Summary

Low-carbon innovations play a key role in the decarbonisation of energy-intensive industries, such as the four key REINVENT sectors, steel, plastics, pulp and paper, and meat and dairy. It is therefore crucial to understand what drives the initiation of innovation processes, and what factors either foster or hinder their success. Drivers and barriers may be of a technical nature. However, this analysis shows that most of the drivers and barriers can be generalized to process- or product-specific ones. Non-technical aspects often influence innovation in more than one sector. During Task 3.4 of the REINVENT project, both sector-specific and cross-sectoral drivers and barriers of low-carbon innovation were subjected to analysis, the results of which are summarised in this report.

A qualitative analysis of 18 in-depth innovation case studies and five innovation biographies regarding different sub-categories of drivers and barriers provided the basis for this work, supplemented with the information on drivers contained in the REINVENT innovations database, which includes a total of 122 innovations from they key REINVENT sectors. The identified drivers and barriers were aggregated on a sectoral level and attributed to the value chain stage(s) on which they exert the bulk of their influence. As a final aggregative step, those drivers and barriers that play an important role across sector lines were identified and summarised, sorted by affected value chain stage(s), and underpinned with examples from different sectors.

Key cross-sectoral influencing factor at the investment stage include cost and duration of R&D, public funding, governmental support and savings to deal with setbacks. Innovation in energy-intensive industries is often associated with high R&D costs and long R&D cycles, leading to great financial risk, which makes targeted public funding and other (non-financial) forms of governmental support crucial at this early stage of the value chain.

At the stages around the production phase (material procurement, production, distribution), innovation is also affected by economic and infrastructural aspects such as the price and availability of 'green' energy and input materials. Innovations are also strongly influenced by factors such as internal organisation, the personal motivation of the actors involved in the process, the networking of (local) actors and cross-sector cooperation – most of which can affect innovation in either a positive or a negative way.

On the consumption end of the value chain, a growing consumer demand for 'green' products is an increasingly strong driver for innovation. Not only current consumer trends, but also expectations or uncertainty surrounding future demand (both from manufacturers and from end consumers) drives and or hampers innovation.

A wide range of influencing factors are not specific to any one stage of the value chain, but can affect innovation at any stage. These include political framework conditions such as existing standards and regulation, expected future regulation, international targets, as well as regional effects, public awareness and stakeholder pressure. Company-specific CSR strategies and considerations of future competitiveness can also be a strong influence on the development of innovations.

These cross-sectoral influencing factors, as well as the sector-specific ones, were presented, discussed and validated at a stakeholder workshop. At the same workshop, a focus group session was held to extend the results from the analysis to the future by discussing the role of key influencing factors for future innovations, steering toward total industrial decarbonisation by 2050. Main focus areas included demand-side changes, new industrial cooperations, and framework conditions. There has already been a visible shift in how low-carbon innovation in energy-intensive industries is

conceived. Many of the past innovations studied in REINVENT were only driven by decarbonisation in an indirect way, if at all. This is changing – and creating the right framework conditions will be crucial for ensuring that future innovations will contribute to industrial decarbonisation.

1. Introduction

After previous Work Package 3 (WP3) tasks involved preparing and conducting an in-depth examination of innovation case studies, Task 3.4 comprises a comparative structured analysis of the rich empirical material generated so far. The focus of this analysis is narrowed to non-technical drivers and barriers of low-carbon innovation, thus returning to the key theme of WP3. In order to validate the results of the analysis, these are presented and discussed in focus groups involving members from the selected industries.

Besides the case studies from Task 3.3 (Deliverable 3.3), data sources include the innovation biographies from Task 2.3 (D2.7) and the decarbonisation innovation database from Task 2.2 (D2.1). In these tasks, analytical work remained mostly on the individual case level, concentrating on different value chain stages and only partially taking a sectoral view. The next logical step is to bring the work to a sectoral and cross-sectoral level.

Hence, the objective of this task is to derive an evidence-based scheme of non-technical drivers (and barriers) of innovations and on potential influencing factors for future low-carbon innovations. This approach aims at revealing patterns, trends and associations, which may support the design and set up of strategies and policies to facilitate future innovations in the considered sectors (as an input for WP6 but also in general).

This deliverable thus focuses on the sector-specific and cross-sectoral drivers and barriers for recent and present low-carbon innovations which could be identified by means of the analysis (Chapter 4 and 5). Furthermore, it is considered how to best deal with some of these drivers and barriers from a future point of view (Chapter 6). In addition to that, the research methodology is explained (Chapter 2) and a short overview of intermediate results is given (Chapter 3). Finally, the outlook (Chapter 7) describes how the results and insights of Task 3.4 could inform and enhance future REINVENT tasks as well as further research, strategic or political activities.

2. Methodology

As mentioned above, the objective of Task 3.4 is to derive an evidence-based scheme of non-technical drivers and barriers of innovations and on potential influencing factors for future low-carbon innovations. The research question to be answered is: What are the non-technical drivers and barriers of innovations and potential influencing factors for future low-carbon innovations?

Therefore, a comparative structured analysis of the results of previous REINVENT work packages has been conducted. The different methodological steps undertaken in the framework of the analysis are shortly introduced in the following and described in more detail further below.

1. Qualitative and partly quantitative content analysis of results of previous work packages
    - 18 case studies from Work Package (WP) 3.3 (summarised in Deliverable (D) 3.3)
    - 5 innovation biographies from WP2.3 (see D2.7) and
    - 122 innovations from the decarbonisation innovation database (WP2.2/see D2.1)
2. Identification of drivers and barriers on a
    - sectoral level (steel, plastics, pulp & paper, meat & dairy) and
    - cross-sectoral level,
3. Discussion/validation of the identified drivers and barriers with stakeholders

2.1. Content analysis of previous work packages

A team of nine project members from different REINVENT research institutions (representing the different participants' expertise) conducted the content analysis, screening case study reports, innovation biographies and the innovation database for different sub-categories of drivers and barriers.

As the 18 in-depth **case study reports** from WP3.3 represent the most comprehensive and detailed data source, the focus lay on analysing those. An overview of the examined case studies is given in Figure 1.

The case studies' visualisation is differentiated with regard to the industrial sector and the stage of the value chain they can be assigned to. The different sectors can be distinguished by colouring (blue = steel, orange = plastics, green = pulp and paper, yellow = meat and dairy). Cases which belong to two sectors are marked accordingly with two colours (e.g. *Carbon2Chem*: steel off-gases are used to make chemical intermediates, an input into plastics production). Overall, there are three to six cases from each industrial sector.

Besides those industry-specific case studies, in the framework of Work Package 3.3 two more cases from the finance sector had been analysed (*Fossil-free churches* (fossil fuel divestment by faith-based actors in the UK, Belgium and Sweden) and *Triodos* (Organic Growth Fund, an investment fund offered by Dutch Ethical Bank Triodos), marked grey). The two finance case studies *Fossil-free churches* and *Triodos* differ from the other 16 case studies in so far as they cannot be attributed to one of the four REINVENT sectors steel, plastics, pulp & paper and meat & dairy. Instead, they cut across these sectors as financing itself can constitute a driver or barrier for decarbonisation innovations in the four sectors. Therefore, they were examined for factors representing potential cross-sectoral drivers and barriers of financing low-carbon projects. The results of this separate analysis are outlined in Chapter 5.2.

The stages of the value chain are represented by the different columns. Cases which could not clearly be assigned to one stage either stretch over more than one stage or fade out at one stage and fade in again at another (e.g. *Äänekoski*).

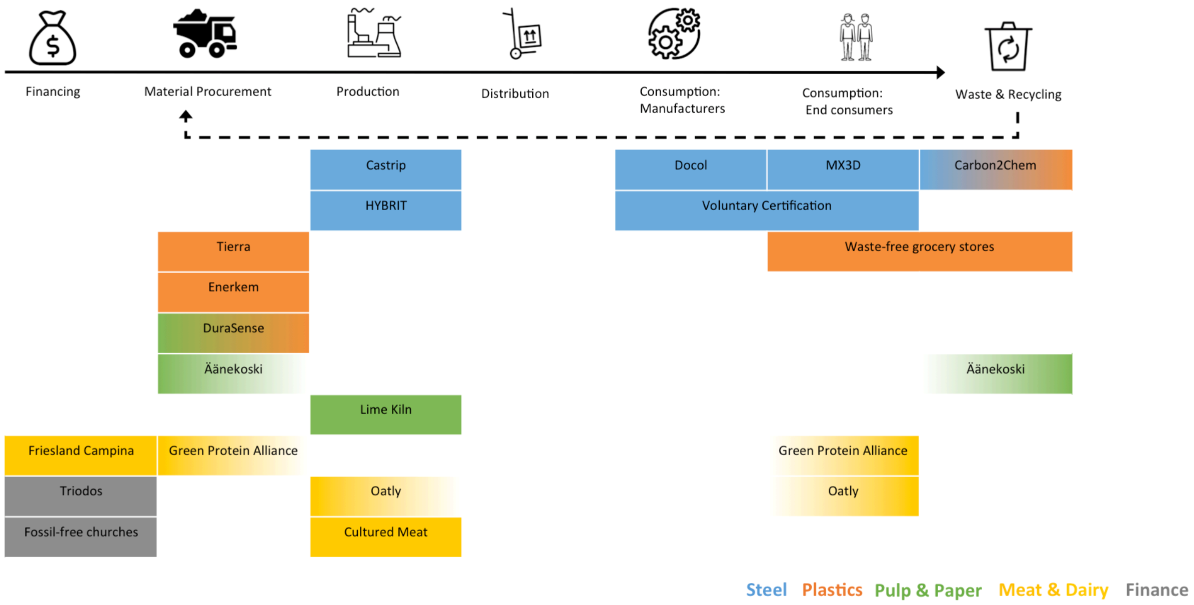


Figure 1: Overview of case studies according to sector and stage of the value chain

The number of **innovation biographies** from WP2.3 to be examined was far lower (five) and they were also considerable shorter in length (four to six pages). Their research objectives could be assigned to the following sectors and stages of the value chain:

- *Oatly* (meat and dairy; production – also topic of a case study, see above),
- *Green Protein Alliance* (meat and dairy; consumption – also topic of a case study, see above),
- *Ojah* (meat and dairy; production),
- *Cardyon* (plastics; production) and
- *LignoBoost* (paper; production).

As the documents produced for both case studies and innovation biographies were written in continuous text, the same methodology could be applied for their qualitative content analyses. In contrast, the WP2.2 **decarbonisation innovation database** is a large table mainly containing 'yes' or 'no' answers or short explanations (as an example see the excerpt from the database in Table 1). This database was analysed mostly quantitatively, as described further below.

	6. DRIVERS OF INNOVATION					
Shorthand name for the innovation	6.5 Corporate social responsibility	6.6 Corporate social responsibility – explanation	6.7 Market deman	6.8 Market demand – explanation	6.9 Technology supply	6.10 Technology supply – explanation
phs-ultraform®	Yes	voestalpine's sustainability target to optimize production plants and technologies on an	Yes	the development of phs-ultraform® was the customers'	No	
phs-directform®	Yes	voestalpine's sustainability target to optimize production plants and technologies on an	Yes	already standard for most press-hardened steel components so	No	
Arcelor's waste tires in EAF	Yes	aimed at reducing emissions, coal demand and tyre waste in landfill - all of which could be	No		No	
Castrip® Process	No		Yes	entails casting metal to a form close to that required for the	Yes	strip casting technology can be attributed to the fact, that it had to
Rotary Hearth Furnace Dust Recycling System	Yes	aimed at reducing energy, costs and efficiently uses resources - all of which could be	No		No	
BSB prefabricated highrise construction	Yes	protecting the environment, energy conservation and reducing greenhouse gases	Yes	Economic Fourm, "more than 90% of China's commercial	Yes	expertise and started applying manufacturing principles to high-rise
ConX®	Yes	technique as Cradle2Cradle products and they promise higher security as well as less	Yes	the building center by manufacturing not on-site but in a production	No	
Strenx™ 700 MC Plus (Strenx™ Performance Steel)			Yes	wanted to be able to lift more with the same or even reduced vehicle	No	
tribond®	No		Yes	demand from the automotive sector in buidling light-weight	No	

Table 1: Excerpt from the decarbonisation innovation database

2.1.1. Case studies (WP3.3) and innovation biographies (WP2.3)

In order to derive the drivers and barriers for low-carbon innovation from the case studies and innovation biographies, a mixture of a deductive and an inductive approach was chosen. The deductive part of the analytical process based on previous REINVENT work:

On the basis of literature research and previous REINVENT reports, a driver for low-carbon innovation was defined as 'a resource, process or condition that is vital for the initiation, continued success and/or growth of an initiative.' With regard to the main categories of drivers and barriers, first a set of sub-categories was derived for **drivers** from the innovation database from Work Package 2:

- Government regulation, legislation and planning guidance;
- (Voluntary) Standards and targets;

- Corporate social responsibility;
- Market demand;
- Technology supply;
- Material properties;
- Stakeholder pressure

A **barrier** was defined as ‘something such as a rule, law, or policy that makes it difficult or impossible for something to happen or be achieved/something that prevents something else from happening or makes it more difficult.’ The original set of barriers stems from an empirical investigation of barriers, drivers and practices for energy efficiency in primary metals manufacturing SME (Trianni, Cagno & Farnè, 2014):

- economic
- information
- organisational
- behavioural
- awareness
- competences
- technology-related

In addition to the main categories of drivers and barriers, two more main categories were included in the analysis: Instruments/activities and cross-industrial interdependencies.

The category **instruments/ activities** aimed at making sure that also ‘potential influencing factors’ (as written in the REINVENT proposal) which did not ideally fit into one of the other main categories were considered for the analysis. Thus, the category was defined broader, comprising ‘All kinds of actions, tools or instruments (political, fiscal, …) that are used or needed in order to overcome challenges or to achieve or cause something. These instruments can be successful as well as failed. Activities comprise all actions or tools that were used with a non-direct effect and cannot be classified as a regulatory, economic or planning law instrument’. The established sub-categories were:

- successful instruments/ activities
- failed instruments/ activities
- regulatory instruments
- economic instruments
- planning law instruments
- informal instruments/ activities

Later in the process, when actually comparing the results of the content analysis on a sectoral and cross-sectoral level, it was concluded that in fact everything allocated to this category could also be classified as a driver or barrier. The category therefore does not appear anymore in Chapters 4 and 5.

The category **cross-industrial interdependencies** should secure results of interest for the cross-sectoral examination of drivers and barriers of low-carbon innovation (see Chapter 5). According to the category’s definition, ‘Cross-industrial interdependencies between sectors may arise through material substitutions, resource flows, collaborations, new forms of consumption, etc. This category comprises cross-industrial interdependencies between the REINVENT sectors but also towards other sectors along the value chain of the REINVENT sectors (as waste or water management industry).’ At the beginning of the process, no sub-categories were determined for this main category.

After a first round of case study analyses, the sub-categories have been revised by the team to ensure they comprehensively represent the findings from the content analysis. This represents the inductive part of the methodological approach. In the course of the analysis, the following sub-categories were added to the main categories:

Drivers:

- economic incentives
- geographies
- organisational

Barriers:

- regulation
- geographies
- materials
- market demand

Instruments/ activities: no additions

Cross-industrial interdependencies:

- inter-industrial collaboration
- cross-industrial collaboration
- competition
- value chain interdependency

For the actual qualitative data analysis, some researchers used the software MAXQDA for coding text segments, others did so manually. When the analyses of the case studies and innovation biographies had been concluded, the outcomes were merged in result files, according to main categories (drivers, barriers, instruments/activities and cross-sectoral interdependencies) and their respective sub-categories. These results represented the basis for the analysis on the sectoral and cross-sectoral level.

2.1.2. Decarbonisation innovation database (WP2.2)

Entries into the WP2.2 decarbonisation innovation database were made in the form of a large table comprising many categories (as depicted in Table 1). Whether a certain driver did or did not play a role for a particular low-carbon innovation was answered either by 'yes' or 'no'. In addition to that, a short explanation could be entered. The categories of potential drivers were predefined and not subject to change. Since the first set of driver sub-categories for our content analysis was derived from the innovation database, the driver sub-categories included in the database equal those mentioned at the beginning of this chapter. If an additional kind of driver fostered an innovation from the database, this could be categorised as 'other'.

For the quantitative analysis of the decarbonisation innovation database, it was examined how often a specific kind of driver played a role for an innovation in a particular sector.

In addition to the quantitative analysis, the explanations added with regard to the drivers of innovation were also taken into account. They were examined along with the qualitative results from the analysis of the in-depth case studies and the innovation biographies.

2.2. Identification of drivers and barriers on a sectoral and cross-sectoral level

The analysis of drivers and barriers to low-carbon innovation on a sectoral level bases on the result files from the content analysis described above. It was examined in how far manifestations of the different sub-categories constituted a driver not only in one, but in several of the cases analysed. If a factor was considered important on a sectoral level, it was described as precisely as possible while making sure that it still captured the results from the different case studies. In a next step, all identified sectoral drivers and barriers were categorised according to that/those stage(s) of the value chain on which they exerted their greatest influence. The results of this exercise were visualised for the steel, plastics, pulp & paper and meat & dairy sectors in figures included in Chapter 4.

Based on the results for the particular four sectors, the same methodology was applied to analyse drivers and barriers which play a role for decarbonisation innovations on a cross-sectoral level. After being identified and summed up in one terminology, they were also depicted in a figure (see Chapter 5).

2.3. Validation of results with stakeholders

Draft results from this process were then discussed in an internal two-hour webinar with other REINVENTERs on 15th August 2019. Following this feedback, the results were slightly revised and augmented.

As a last (validation) step, the identified drivers and barriers were presented, discussed and evaluated in a one-day workshop format including both REINVENT researchers and nine external stakeholders with sectoral expertise from industry, research and NGOs. This workshop took place on 16th September 2019 in Düsseldorf and included a focus group session in the afternoon, during which participants were split into three groups to expand the discussion on cross-sectoral drivers and barriers, taking a 2050 perspective.

In earlier iterations of the focus group concept, it was envisaged to have four focus groups, split strictly along sector lines. However, during the course of the analysis it was concluded that taking a cross-sectoral perspective in the focus groups was more valuable and in keeping with the overall logic of the work package, as the sectoral view has already been well covered in Task 3.3. The project review confirmed the importance of bringing REINVENT work to a cross-sectoral level. It also highlighted the necessity of taking a 2050 perspective, which was worked into the conceptualisation of the focus groups as well.

Consequently, the first part of the workshop (morning session) was used to present, discuss and validate the sectoral and cross-sectoral drivers and barriers that were derived from the analytical process. Here, a more *historical* perspective was taken (resulting from the fact that the studied innovation processes took place in the (recent) past) and balanced with the stakeholders' feedback on their *current* relevance. As external stakeholders from different sectors jointly evaluated the identified drivers and barriers, discussion took mostly place on a cross-sectoral level. Therefore, results from this discussion are integrated into Chapter 5.1 on cross-sectoral drivers and barriers.

The focus groups (afternoon session) were then conceptualised to take the discussion to a *future* (2050) perspective. The theme for each focus group comprised a potential influencing factor (or a set of related potential influencing factors) evolving from the comparative analysis and chosen based on their perceived future relevance and their importance to REINVENT work. As three such dominant themes emerged, and as the number of participants became known (fourteen external stakeholders signed up), it was decided that having three instead of four focus groups seemed reasonable. The topics of these focus groups were as follows:

- Focus Group I: Changing demand side and lifestyles
- Focus Group II: New industrial cooperations and a change of traditional sector views
- Focus Group III: Framework conditions – economic incentives, government regulation and technical/infrastructural standards

Participants were free to choose which focus group to join. As is typical for the format, discussions were kept fairly open. Each focus group was led by two REINVENT researchers who asked some guiding questions if necessary. Participants were asked to picture decarbonised industries in 2050 and discuss how this will have been achieved, within the thematic realm of their particular focus group topic. Discussion results are summarised in Chapter 6.

3. Non-technical drivers and barriers identified in previous work packages

After describing the methodology for the content analysis in detail in Chapter 2.1, an overview of the results will be presented in this chapter. It is confined to the most important information and specific examples illustrating the form of the results. This proceeding is due to the fact that the results of the content analysis were mainly destined as a data source for the sector-specific and cross-sectoral examination. Therefore, in this report the focus is laid on the following analytical step, the results of which are presented in Chapter 4 (sector-specific drivers and barriers) and Chapter 5 (cross-sectoral drivers and barriers). Another reason for this proceeding is that especially the content analysis of the in-depth case studies produced a very large amount of data which can hardly be integrated into a report.

3.1. Results content analysis case studies and innovation biographies

The outcome of the content analysis of the in-depth case studies were result tables in the form of the following excerpt from the *Enerkem* (plastics) case study result table. These tables show the coded segments from the case studies as assigned to sub-categories (here: government regulation, legislation and planning guidance; (voluntary) standards and targets; corporate social responsibility) of the main categories (here: drivers). The third column comprises a summary of the coded segments in the column to its left. Comparable tables also resulted from the content analysis of the other 17 case studies.

Code	Coded segment	Summary
Drivers		
Government regulation, legislation and planning guidance	timing seems to be driven by European regulatory developments on biofuel standards While it was '[i]nitiated through progressive waste policy', it 'also supports wider [EU, national as well as local] policy objectives'(Miles, 2018a). With regard to the progressive waste policy in the Netherlands, Miles (2018a)mentions two important pillars. Firstly, there is a waste disposal tax of EUR 13.07 per 1,000kg applying to waste which is landfilled or incinerated. Meanwhile, nothing has to be paid for waste being recycled(Government of the Netherlands, n.d.). Secondly, 'chemical recycling' is explicitly recognised as a form of recycling in Dutch waste legislation (see the National Waste Management Plan enacted on 28 November 2017, dubbed LAP3). The overview shows that in general, there is a favourable policy environment in the Netherlands regarding circular economy efforts. Among those policies targeting energy and climate issues, an EU Directive carries great weight for the decision on the Enerkem Project in Rotterdam. This is the EU Directive 2018/2001 of 11 December 2018 on the promotion of the use of energy from renewable sources, the recast of the so-called 'Renewable Energy Directive' (REDII) (EN5b). Current policy (e.g. EU recast of Renewable Energy Directive, progressive waste policy in the Netherlands) and potential future regulation on different levels represent a very important driver for the initiation of the project.	- progressive waste policy in the Netherlands - adoption of recast of EU 'Renewable Energy Directive' which requires a certain level of biofuels e.g. from waste in the future'
(Voluntary) Standards and targets	As depicted by the Province of Zuid Holland (see Figure 7), the project was initiated at the beginning of 2016. An important trigger might have been that around that time Enerkem's waste based biofuels had obtained certification from the International Sustainability and Carbon Certification system. Hence, they had been approved for sale in Europe (Messenger, 2016).	- Enerkem's biofuels obtained certification from the International Sustainability and Carbon Certification system
CSR	The technology was originally developed by Dr. Esteban Chornet at Université de Sherbrooke (Quebec, Canada) (now retired) who aimed at solving the problem of waste disposal and also achieve low carbon transportation (EN2).	- Enerkem founder strived for positive environmental impact

Table 2: Excerpt from the result table of the *Enerkem* case study content analysis

Since the same method of analysis was applied for the content analysis of the five innovation biographies, the result tables resembled those from the case studies. However, result tables from the innovation biography analysis included fewer coded segments because compared to the case studies, they were considerably shorter in length (only four to six pages). The excerpt in Table 3 stems from the result table of the content analysis of the *LignoBoost* (pulp and paper) innovation biography. Again, coded text segments were attributed to the sub-categories of drivers, barriers, instruments/activities and cross-industrial interdependencies.

Categories	Sentence
Drivers	
Government regulation, legislation and planning guidance	
(Voluntary) Standards and targets	the pulp and paper industry's commitment over the past 10 years to making the production process of pulp and paper less energy intensive by focusing on energy efficiency and energy surplus, thereby incentivizing the development of CO2 emissions saving technologies
Corporate social responsibility	
Market demand	Despite an increase in electronic and digital communications, the industry continues to grow, with production expected to reach 490 million tonnes by 2020 (Bajpai, 2014). Much of this growth actually goes hand in hand with the rise in digitization, as packaging and shipping material use continues to grow alongside online shopping.
Technology supply	The key element in this innovation is the washing process, as other innovations have figured out how to remove black lignin, but none have been able to return it to such a clean state. The Domtar mill has an annual capacity of 466,000 ADMT of softwood kraft pulp. The LignoBoost technology allowed the mill to de-bottleneck its recovery boiler and sell the pulp. The process proved immediately beneficial to the mill, serving as a fuel for its own use and a funding source (Valmet, undated).
Material properties	
Stakeholder pressure	
Barriers	
economic	While Valmet has goals of selling more plants in the future, a current obstacle facing their sales is that many potential customers are unsure what exactly to do with the clean extracted lignin. This uncertainty makes investment calculations difficult and the result is a reluctance to purchase.
information	

Table 3: Excerpt from the result table of the *LignoBoost* innovation biography content analysis

The result tables of the content analysis of the in-depth case studies and innovation biographies were then analysed on a sectoral and, subsequently, cross-sectoral basis. This rich data source was complemented by the results of the analysis of the decarbonisation innovation database.

3.2. Results content analysis decarbonisation innovation database

The decarbonisation innovation database was mainly analysed quantitatively. It was examined how often a specific kind of driver played a role for an innovation in a particular sector. The results are displayed in Table 4.

Drivers of Innovation	Pulp & Paper	%	Plastics	%	Steel	%	Meat & Dairy	%
Total Innovations	30		33		25		34	
Government regulation, legislation and planning guidance	6	20%	6	18%	6	24%	8	24%
(Voluntary) Standards and targets	3	10%	3	9%	1	4%	3	9%
Corporate social responsibility	14	47%	18	55%	16	64%	14	41%
Market demand	9	30%	6	18%	15	60%	12	35%
Technology supply	3	10%	8	24%	5	20%	1	3%
Material properties	9	30%	4	12%	3	12%	1	3%
Stakeholder pressure	3	10%	8	24%	2	8%	5	15%
Other	2	7%	2	6%	5	20%	1	3%

Table 4: Importance of different drivers for decarbonisation innovations in the pulp and paper, plastics, steel and meat and dairy sectors

It should be noted that such a quantitative result does not provide information regarding the importance of the driver for the specific innovation.

As described in Chapter 2.1.2, the explanations added to the database with regard to the drivers of innovation were also taken into account. They were examined along with the qualitative results from the analysis of the in-depth case studies and the innovation biographies.

Besides the lack of weighting inherent in the quantitative analysis, also no information regarding barriers to innovation had been included in the database. Hence, altogether the in-depth case studies and the innovation biographies provided a much richer source of information on drivers and barriers to low-carbon innovations in the four REINVENT sectors. Therefore, results from the analysis of the database did not represent the main source of data for the content analysis but rather complemented it.

4. Sector-specific drivers and barriers of low-carbon innovation

After working out the non-technical drivers and barriers identified in previous work packages, they have been analysed from a sectoral point of view. In the following, the results of this analysis are presented. Drivers and barriers playing a role for decarbonisation innovations in several case studies are described for each sector. It should be noted that, while being comprehensive, the results of our analysis are derived from specific case studies and thus cannot automatically be applied to every low-carbon innovation from the particular sector.

4.1. Steel

The analysis of drivers and barriers of low-carbon innovations in the steel sector is based on the content analysis of the following six case studies:

- *HYBRIT* (primary steelmaking with hydrogen direct reduction)
- *MX3D* (3D-printed steel bridge)
- *BREEAM* (voluntary certification schemes for materials in buildings)
- *Castrip* (strip casting technology)
- *Carbon2Chem* (production of chemicals from captured steel off-gases)
- *Docol* (lightweight automotive steel production)

Additionally, the quantitative analysis of the decarbonisation innovation database was taken into account.

Those drivers and barriers which either fostered or hindered decarbonisation innovations in several of the case studies are displayed in Figure 2 below. While many influences could be clearly identified as drivers (in green boxes) and others as barriers (in red boxes), certain factors affected decarbonisation innovations both ways. These potential drivers or barriers are shown in boxes turning from green to red. Furthermore, each factor is assigned to that stage of the steel value chain on which it exerts the biggest influence. If this is true for several stages, the box extends to the respective steps up to the whole value chain.

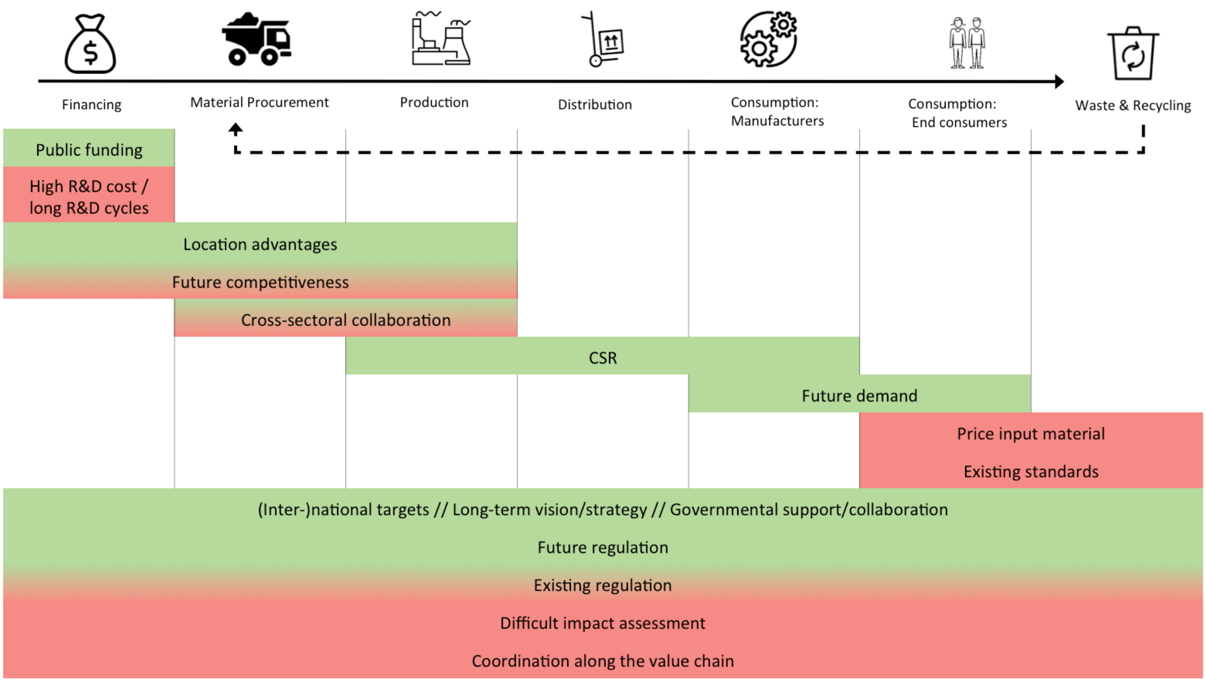


Figure 2: Drivers and barriers in the steel sector according to their influence on stages of the value chain
Key: Driver = green, barrier = red, potential driver or barrier = green to red

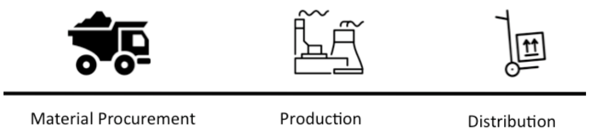
Considering their assignment to the different stages of the value chain, the identified drivers and barriers are described in further detail in the following. Specific examples from the analysed case studies are given for illustration purposes.

Public funding

Public funding can be a significant driver at the investment financing stage of steel innovations, helping to mitigate what may otherwise be prohibitive levels of business risk. In the case of *HYBRIT*, substantial financial support from the Swedish government is deemed crucial to success. The *Swedish Energy Agency* funds the different projects included in the *HYBRIT* initiative with 30 to 50 per cent. Most of the funding comes from the *'Industriklivet'* programme *('The Industry Step')*, which the government initiated in 2018. The Swedish government financing of steelmaker SSAB also played a role in the *Docol* case, as SSAB is the supplier of *Docol*. The *Carbon2Chem* project benefitted strongly from a shift in the *German Federal Ministry of Education and Research*'s funding focus, which favours this type of large-scale project with comparatively short-term implementation.

High R&D cost / long R&D cycles

In the steel industry, innovation cycles are long and R&D is costly. Process innovation is hindered by very long equipment lifetimes and high investment costs, especially when it comes to bringing innovation to an industrial scale. In the case of *Castrip* for example, many competing technologies failed to reach industrial scale because they were unable to secure the necessary funding to take this leap. *Castrip* only succeeded because *Nucor*, as an operator of small-capacity 'mini mills', stood to gain access to new market segments by being able to produce strip steel on-site and was thus willing to take on the risk. However, this barrier continues to play a role for further up-scaling: Bringing strip-casting technology to the scale of an integrated steel plant would mean replacing both a continuous caster and a hot rolling mill at the same time. Both have high investment costs and lifetimes spanning several decades, so installing a strip caster would only make economic sense if both need replacing around the same time. So even if technical issues of up-scaling the technology could be overcome, these circumstances make it difficult for large integrated steelmakers to invest in such a technology in the first place. This is only one example of how these specific industry characteristics create inertia and hinder low-carbon innovation. Long periods of insecurity and a missing business case are the result, meaning that projects such as *Carbon2Chem* or *HYBRIT* would be highly unlikely to happen without public funding.



Location advantages

For a centralised industry such as steel, location can play a big driving role for low-carbon innovation. *HYBRIT*, for example, benefits from the conditions of the Swedish steel industry, including the availability of low-carbon electricity as well as iron ore, and a high level of specialisation of the steelmaking companies leading to very low levels of competition and thus favouring a joint undertaking like the *Swedish Steel Association*'s vision, which led to the creation of the *HYBRIT* initiative. For *Carbon2Chem*, the existing steel and chemical clusters of North Rhine-Westphalia made the project feasible in the first place.

Future competitiveness

Case studies such as *Carbon2Chem* show that, among other things, the Paris Agreement was a milestone event that brought with it the understanding that deep decarbonisation of energy-intensive industries is inevitable, and achieving it as a company is a question of survival. There has been a shift in steelmakers' stance on emissions reductions, leading to a general understanding that energy-efficiency improvements to existing processes will not be sufficient in the long run. Investing in innovation for decarbonisation is therefore driven by a desire to remain competitive in a zero-carbon economy.

Medium-term future competitiveness, especially on a global scale, can also be a barrier. For *HYBRIT*, the technology's economic competitiveness has been identified as a main challenge. The uncertainty of whether a market for low-carbon steel will exist in the future, and at what scale, makes it difficult to construct a business case for the technology, which will be unable to compete as a commodity with cheap steel from conventional production.

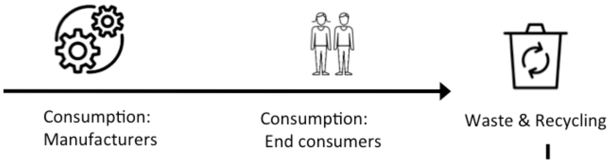
Cross-sectoral collaboration

Cross-industrial collaboration can be a strong driver for low-carbon innovation. In the case of *Carbon2Chem*, steel and chemical companies coming together was a prerequisite for the project's initiation and the development of the technology. Likewise, the *HYBRIT* initiative's success so far is attributed in no small part to very close collaboration between the involved companies from different sectors. The project builds on well-developed trust and collaboration, particularly between *SSAB* and *LKAB*.

The requirement of close collaboration in big R&D consortia can also be a barrier to innovation. It can lead project partners to proceed with caution, potentially slowing down innovation and/or making it less effective. In the *Carbon2Chem* project, this barrier was particularly prominent in the initiation phase and significantly prolonged the preparation and signing of the necessary contracts. The project's novelty and complexity as well as issues of compliance and competition law amplified this problem.

Corporate social responsibility

Corporate Social Responsibility (CSR) policies and strategies at company or industry level – and any self-imposed visions or goals resulting from them – can positively contribute to low-carbon innovation. The Swedish steel industry, for example, has a goal to shed its reputation as being Sweden's top emitter by becoming part of the solution, rather than remaining part of the problem. The *HYBRIT* project is a step in that direction. In the *Carbon2Chem* project, the fact that the companies involved joined the project based on their own company-internal motivation, was highlighted and identified as a crucial contributing factor to the project's continued success. While governmental actors initiated the collaboration, the participating businesses are volunteers, not recruits. CSR policies can also create pressure to innovate if they originate from companies further down the value chain. In the case of *BREEAM*, many larger public sector and commercial organisations require certification as part of their procurement strategies in order to align with their CSR policies. This drives developers to prioritise *BREEAM* certification, who in turn will pass on these requirements to their suppliers. CSR strategies were a driver for the vast majority of innovations in the REINVENT database, often in the form of companies' self-proclaimed environmental or social goals.



Future demand

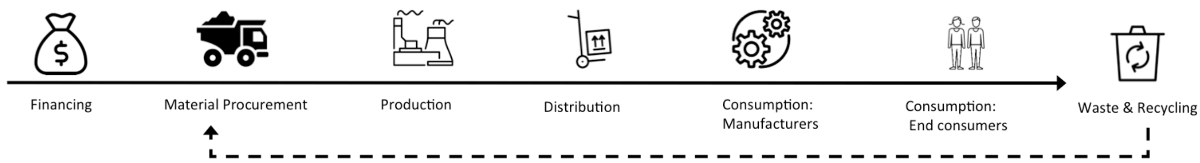
While there is not yet a significant demand for low-carbon basic materials, expected future demand can drive companies to invest in low-carbon innovation now. In the case of *Carbon2Chem*, there is an expectation that a future demand for low-carbon steel may develop, not just as an alternative to conventional steel, but also to other materials that cannot be produced in a CO_2-neutral manner. For *MX3D*, the expected requirements of a more flexible and decentralised production could lead to increased demand for in-house repair and quick and accessible spare parts for machinery, a foreseen future demand that could be met with 3D metal printing technology. As for the innovations in the REINVENT database, market demand was a driver for the majority of them. While for some, this demand was already there (e.g. demand for high-strength steel from the crane industry drove the development of Strenx Performance Steel), for many others it was an expected future demand for more efficient, less CO2-intensive and more light-weight solutions that drove innovation.

Price input material

Steel is a comparatively cheap material, so incentives to increase material efficiency on the consumption side are not very high. This is a barrier for innovations such as *MX3D*, as two of the technology's key advantages are low material use and avoidance of production scrap. Especially for construction purposes, safety concerns tend to lead to an overuse of steel, and potential cost savings are usually too small to de-incentivise these practices.

Existing standards

Existing standards around steel use can prove a barrier to low-carbon innovation. In the case of *BREEAM*, such barriers include the fact that re-used steel is not CE-marked which is seen by developers as a risk/threat, as well as health and safety standards standing in the way of dismantling steel in buildings for re-use. In many nations the government protects the domestic steel industry, hampering the use of foreign advanced high strength steels (AHSS). For *Docol*, this barrier is particularly high, as it is even more specialised than most AHSS.



(Inter-)national targets

National or international decarbonisation targets can be a strong signal that drives innovation. The Swedish aim to reach net-zero emissions by 2045 and the Paris Agreement were stated to be among the main drivers for the initiation of the *HYBRIT* project. In the case of *Carbon2Chem*, the Paris Agreement was stated to have been a 'wake-up call' for both industry and politics to take concrete steps towards deep decarbonisation, thus driving the project. (Inter-)national targets also drove some of the innovations in the REINVENT database: A Chinese government target to ensure that 50%

of new construction are certified green buildings was a driver for BSB, a company specialising in modular construction of high-rise buildings.

Long-term vision/strategy

Company or industry-wide long-term visions, such as the Swedish Steel Association's vision to contribute only positively to society, can foster big long-term R&D initiatives like *HYBRIT*. In other cases, such visions are less explicit but nevertheless stated to be a contributing factor, e.g. *Carbon2Chem*, where CO2 neutrality became part of the industries' long-term visions, motivating them to start acting toward that common goal.

Governmental support/collaboration

Government bodies can play a significant role, even aside from funding and regulation. In many cases, there were different forms of support or collaboration (either in addition to funding/regulation or as solitary measures) that helped foster innovation. For *Carbon2Chem*, the government's role in getting important actors to come together was crucial to the project's initiation. In the case of *MX3D*, the City of Amsterdam opened doors for the start-up's technology and even became its 'first costumer,' purchasing their 3D-printed bridge. In the case of *Docol,* the government supported the innovation by setting higher standards for cars and supporting the idea of a green economy.

Existing regulation

Regulation on a national or EU level can be a significant driver for low-carbon innovation. *HYBRIT* benefitted from the fact that current Swedish climate policies make investment in new blast furnaces not feasible, so alternatives are needed for upcoming re-investment periods. For *Carbon2Chem*, the European Emissions Trading System (ETS) as well as the German government's 2050 Climate Protection Plan were important drivers. Regulation played a role for several innovations included in the database, e.g. a French law on the recovery of used tyres drove the use of waste tyres in Electric Arc Furnaces by ArcelorMittal.

In the case of *BREEAM*, there was a lack of follow-through on proposed UK regulation, which made way for voluntary certification, which tends to be both less strict and less effective. So while the gap left by the proposed law acted as a driver for a voluntary certification scheme, the return to the existing state of regulation (or lack thereof) eventually made low-carbon innovation in the sector less effective. For *MX3D*, there were stated to have been large bureaucratic hurdles that were disproportionate to the size of the project and difficult to handle for a small start-up.

Future regulation

Next to existing regulation, expectations for future regulation can also serve as a driver to low-carbon innovation. For *Carbon2Chem*, the future development of the EU ETS, particularly the expected price increases in the next trading period, has driven the project.

Difficult impact assessment

Measuring an innovation's actual impact on carbon emissions can be rather tricky, which can slow down decision-making and scaling. For *BREEAM*, one major barrier lay in the difficulties of measuring embodied life cycle emissions of buildings due to complex, incomplete and/or low-quality data. In the case of *MX3D*, it is difficult to make generalised statements regarding the technology's potential to cut emissions, seeing as it depends greatly on the application and the alternative manufacturing process.

Coordination along the value chain

Innovation that involves actors at more than one stage of the value chain often requires a high level of coordination between these actors, which brings issues of asymmetric information and high transaction costs. For *BREEAM* certification, there is a lot of coordination required between all stages of the value chain (asset owners, advisors, contractors, suppliers), which can be a barrier to implementation. In the case of *Docol*, every automotive manufacturer brings their own specifications and product certification requirements to the table. For SSAB as the supplier of *Docol*, this means incurring high costs to meet these individual requirements and therefore taking on high levels of risk for every project.

4.2. Plastics

The analysis of drivers and barriers of low-carbon innovations in the plastics sector bases on the content analysis of the following five case studies and one innovation biography:

Case studies:

- *Tierra* (development of a 100% bioplastic-based outdoor jacket)
- *Enerkem* Rotterdam (production of methanol for chemicals and fuel from residual waste)
- *Waste-free grocery stores* (sale of retail goods primarily in bulk without single-use packaging)
- *Carbon2Chem* (production of chemicals from captured steel off-gases)
- *DuraSense* (innovative bio-composite, made of cellulose fibres, wood particles, and plastic; multi-purpose use)

Innovation biography:

- *Cardyon* (raw material for flexible polyurethane foam that contains up to 20% CO_2 as feedstock)

Additionally, the quantitative analysis of the decarbonisation innovation database was taken into account.

Those drivers and barriers which either fostered or hindered decarbonisation innovations in several of the case studies are displayed in Figure 3 below. The colouring mirrors that of the figure in the steel chapter, so does the categorisation according to different stages of the value chain.

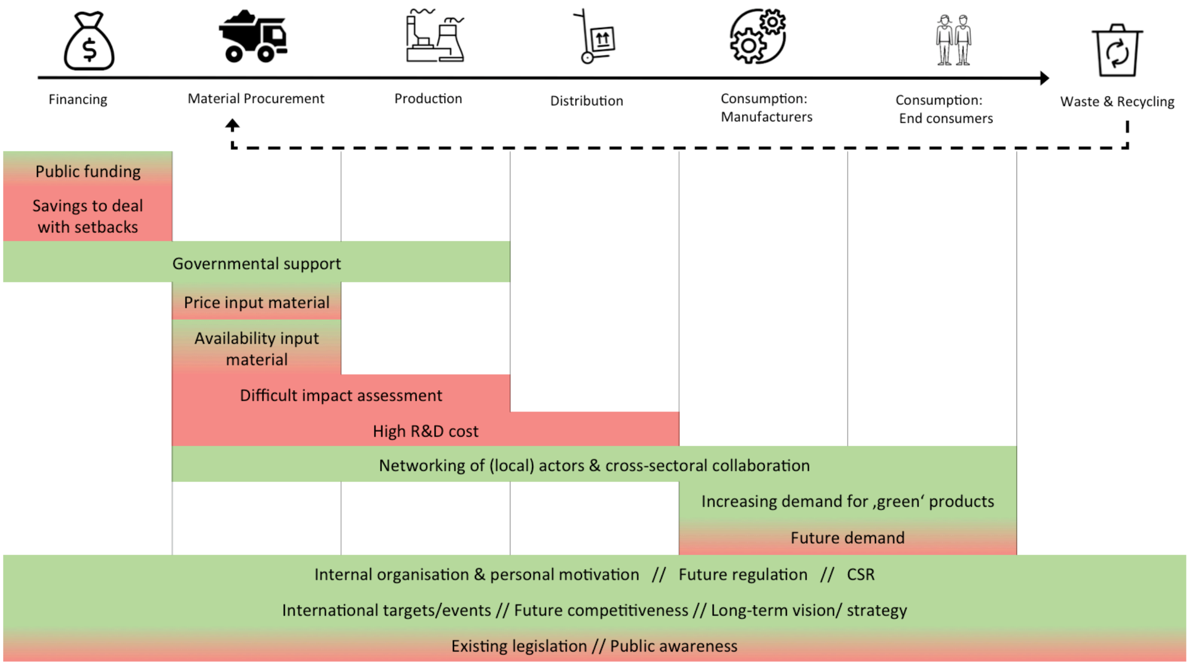


Figure 3: Drivers and barriers in the plastics sector according to their influence on stages of the value chain
Key: Driver = green, barrier = red, potential driver or barrier = green to red

Considering their assignment to the different stages of the value chain, the identified drivers and barriers are described in further detail in the following. Specific examples from the analysed case studies and innovation biography are given for illustration purposes.

Public funding

Financial grants by governments, regions etc. often help to fund innovative projects for which the high business risk makes it hard to receive credits from private institutions. Public investments also indirectly helps secure the competitiveness of resident companies, e.g. the Swedish state's financing of research on sustainable garment production.

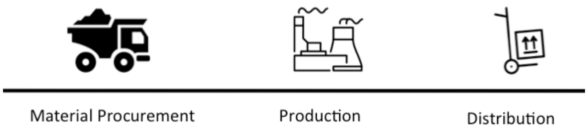
In the case of projects with a high technological risk, public funding opportunities are sometimes considered too low to actually help mitigate the business risk. In the case of *Enerkem* in Rotterdam, consortium members criticised that the availability of public funding did not significantly influence the companies' decision to advance the innovation project. Acquiring public grants was linked to many requirements and in general public entities appeared as risk averse as private financial institutions.

Savings to deal with setbacks

Researching and developing new processes and products usually involves a lot of trial and error and a successful outcome is not guaranteed. Navigating this uncertainty financially is especially difficult for smaller companies without much equity capital, as in the case of *Tierra*. As a result, some companies decide to refrain from such innovation processes if the business risk is not born by other stakeholders (e.g. through public financial support). In the case of *Enerkem* Rotterdam, the required capital could be provided by big multinational firms which are part of the consortium (AkzoNobel Specialty Chemicals (now Nouryon), AirLiquide, Shell).

Governmental support

In many cases governmental support is not only provided by means of direct financial grants but also organisational help, networking activities etc. In order to foster the national sustainable textiles industry involving Tierra (plastics), the Swedish government e.g. launched a platform promoting cooperation between academia and industry. The federal government of North Rhine-Westphalia helped bringing together the companies which later formed the Carbon2Chem consortium (steel/plastics).



Price input material

If a company aims at producing a more sustainable product, this often requires changing the type of material or intermediate good used as an input. Whether or not this step is taken significantly depends on the price of the input material and potential alternatives. In the case of *Tierra*, e.g., a fabric supplier decided to switch and base its complete future production on recycled polyester. A crucial factor in this decision was the recycled material’s marginal price difference compared to virgin material. Another example provides the history behind the *Enerkem* waste-to-chemicals technology: Research on the use of waste as a feedstock for chemical intermediates received much attention when oil prices peaked in the 1970s.

However, as soon as the oil price fell again, interest in developing a waste-to-chemicals process decreased simultaneously. In another case, outdoor company *Tierra* pays higher prices for ‘greener’ input materials for its bioplastics jacket. They try to compensate this by using less fabric (e.g. designs with fewer pockets) in order to not let prices for final customers rise too high.

Availability input material

Besides the price, also the availability of alternative input materials or intermediate goods for production processes can be a decisive factor. In the case of *Enerkem* Rotterdam, e.g., material procurement for the waste-to-chemicals facility is significantly facilitated by the fact that already a lot of waste is being shipped through the Port of Rotterdam. Representatives of the consortium stated that securing contracts with waste suppliers was rather easy and that supply offers exceeded demand. In addition, waste is generally comparatively cheap and readily available in many locations. The *DuraSense* bio-composite bases on the company’s conventional material input (wood fibres) and can be produced by using different matrix materials: different conventional fossil, biobased and recycled polymers.

In contrast, e.g., *waste-free grocery stores* often face limited supply options as only so much organic food is locally available. Interviews from the *Tierra* case study show that due to low previous demand, producers simply did not offer much fabric from bioplastics. By means of an inter-industry cooperation, small outdoor companies thus jointly ordered larger volumes and thereby managed to achieve critical order quantities.

Difficult impact assessment

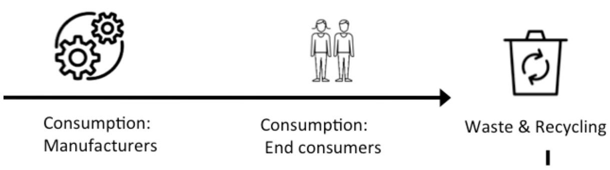
Sometimes companies hesitate to invest in potential innovative products or processes as it is difficult to assess whether these are indeed as sustainable as they appear to be. This is especially important if more than one sustainable option is being discussed and researched, such as bioplastics and recycled plastics. As a result, decisions for a 'greener' product or process are postponed to a subsequent date when the different options' environmental impacts have been subject of further research. While Tierra representatives stated the lack of information on the sustainability of bioplastics as an obstacle, the company decided to proceed on this pathway nevertheless. In the case of *Enerkem*, the actual future GHG emission reduction to be obtained by the waste-to-chemicals process is also hard to determine. It depends, e.g., on the composition of the input waste as well as on the exact configuration of the production process.

High R&D cost

Low-carbon R&D processes in the plastics sector usually involve changes in the production process. These are often accompanied by modifications of material procurement and product distribution processes, specifically in terms of logistics and the required infrastructure. The establishment and building of new structures comes at (often high) costs and hence represents a disadvantage compared to incumbent players using existing structures. This constitutes another potential barrier for market entrants or changing business models. The implementation of carbon capture and usage (CCU) in the *Carbon2Chem* project e.g. requires infrastructure for capturing steel off-gases. Moreover, new production facilities and distribution infrastructure, such as gas pipelines, have to be built. In the case of *waste-free grocery* stores, new supply chains have to be established (in comparison to large retailers).

Networking of (local) actors & cross-sectoral collaboration

Enhanced communication and networking among industry representatives but also among actors located in one region or city often contributes to the initiation of innovation processes. Thereby, personal exchanges help overcome barriers such as lack of information and lack of mutual trust. Ideas on new projects can be discussed and first steps for their implementation initiated. Owners of the *waste-free grocery stores* e.g. exchange information via storeowner networks. *Tierra* employees get into contact with representatives of other Swedish outdoor companies at informal breakfast meetings. For the production of *DuraSense*, Stora Enso initiated cross-sectoral collaborations with firms in the neighbouring region, thus accessing local knowledge and resources.



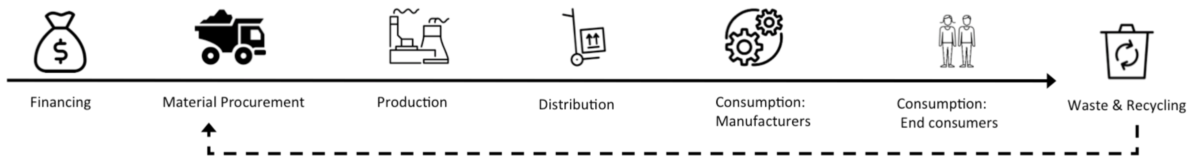
Increasing demand for 'green' products

Rising awareness of the negative environmental impact of many products and processes resulted in rising final consumer demand for more sustainable alternatives. This also led manufacturers to rethink and sometimes change their material inputs towards 'greener' options. The prospect of binding customers or entering new market segments by offering more sustainable products clearly represents a driver for low-carbon innovations. Interviewees in the *DuraSense* case stated that there is an increasing interest in alternatives to conventional plastics (from end consumers as well as in B2B markets, e.g. by IKEA) and that this made it seem economically attractive to further investigate bio-composites. *Enerkem* representatives, e.g., identified a 'consumer pull for renewable and bio-based products' such as 'greener' glues, paints, cosmetics etc. Owners of *waste-free grocery stores* also noted 'more environmentally-conscious consumers'.

Future demand

Innovation processes – which are inherently risky – are only initiated if companies expect future financial rewards from the processes' results. Such rewards usually materialise in form of cost savings and/or income from product sales. Although a product's or process' market potential is usually explored beforehand, actual demand at the time of the product launch can hardly be predicted. This factor can nevertheless be a driver for low-carbon innovation processes, if future demand is secured early by making the prospective customer part of the consortium. The Carbon2Chem as well as the *Enerkem* Rotterdam consortium, e.g., both include future buyers of the chemicals to be produced.

At the same time, concerns over future product demand can also keep companies from developing new, often more costly products. According to *DuraSense* interviewees, the main barrier for using biobased materials is the extra cost which customers are not yet willing to pay. Concerns that customers might be unwilling to pay extra for bioplastic were also articulated by *Tierra* employees. However, other arguments made the company follow the innovation pathway nevertheless.



Existing legislation

Existing legislation can be an important driver or barrier for decarbonisation innovations as it influences investment security for companies. In the case of the *Enerkem* Rotterdam project, e.g., EU legislation on biofuels guarantees a certain future product demand as it requires an increasing share of fuels to originate from renewable energy sources including waste. Furthermore, Dutch waste policy disincentivises landfilling or incineration of waste (by means of a waste disposal tax) while recognising chemical recycling as a form of recycling (thus making it a potential beneficiary of public subsidies).

On the contrary, existing legislation still often eithers favours the extraction and use of fossil fuels or does not punish environmental externalities relating thereto. This makes it economically less attractive to invest in low-carbon innovations. One example is a lack of regulation on the negative effects of plastics which is criticised by owners of waste-free grocery stores. In addition to that, there is still no comprehensive regulatory support for industrial decarbonisation efforts. *Enerkem* Rotterdam representatives, e.g., complain about the lack of comprehensive legislation towards a low-carbon future.

Public awareness

Companies producing and manufacturing 'greener' materials currently benefit from rising societal awareness on climate change and environmental issues. More interest in the topic as well as societal pressure on consumers lead to higher demand for more sustainable products and processes. The growing sales market is an important driver for decarbonisation innovations. Owners of waste-free supermarkets, e.g., notice that consumer awareness of marine litter and micro plastics increased significantly. Similarly, interviewees in the *DuraSense* case stated that the focus on plastics in the environmental discourse has been helpful for working on bio-composites. On the other hand, companies not engaging in decarbonisation efforts might be punished by consumers. As an example, Covestro developed its *Cardyon* raw material due to public pressure to reduce fossil fuel input.

Some environmental problems are covered widely by media outlets while others are considered only rarely or not at all. This also strongly influences public awareness and interest in 'greener' product alternatives. In interviews with *Tierra* representatives, e.g. the lack of public awareness of the fossil fuel origins of textile plastics were mentioned. Demand for the company's bioplastic-based outdoor jacket would probably rise in conjunction with increasing public awareness of the issue.

Corporate social responsibility

Positive contributions to public life as well as the avoidance of negative effects from its products and processes are inherent in most companies' low-carbon innovations. This includes, e.g., the avoidance of greenhouse gas emissions by the Carbon2Chem project where steel off-gases are captured and used as a feedstock for the production of chemical intermediates. Waste-free grocery stores help reducing the demand for plastic packaging production and also littering.

International targets/events

Events and their potential outcomes which receive widespread (media) attention can act as a trigger for the actual initiation of decarbonisation innovation processes. Interviewees from several case studies, such as *Carbon2Chem* and *Tierra*, mentioned that the conclusion of the Paris Agreement constituted a 'wake-up call' respectively starting point for their projects. Covestro mentions a commitment to alignment with the SDGs as a driving force for its *Cardyon* material.

Future competitiveness

Especially companies which heavily rely on fossil fuels do not believe to stay economically competitive in the long term without changing their current business model. Therefore, they invest in low-carbon innovation projects in order to make first steps towards a more sustainable business model. This is true, e.g., for fossil-based companies involved in the *Enerkem* Rotterdam project as well as for partners in the *Carbon2Chem* consortium. In the latter case, an interviewee stated that due to lower GHG emissions, CCU means lower cost from the EU's Emission Trading Scheme (ETS).

Long-term vision/ strategy

Another important driver for low-carbon innovations appear to be business owners or leading managers themselves who see the benefit of more sustainable products and processes. If they adopt long-term strategies and are not put off by setbacks, this often results in successful innovations. This applies to the dedicated owners of *Tierra* and also to the Canadian founder of *Enerkem* who aimed at solving the problem of waste disposal and achieve low-carbon transportation.

Internal organisation & personal motivation

The persecution of 'greener' innovations is often linked to a person's personal values. Many people who engage in decarbonisation innovation projects also do so to contribute to the low-carbon transition. For example, *Tierra* employees had a stated goal of addressing their dependence on fossil fabrics and owners of *waste-free grocery stores* often want to promote sustainable lifestyles. The restructuring of internal processes in the *DuraSense* case shows that organisational change within a company can help moving innovation projects forward.

Future regulation

Linked to a company's future economic competitiveness is also the topic of incoming legislation. Many managers and business owners expect future regulation to become stricter in regards of negative externalities of fossil fuels and fossil-based products. In order to prevent being caught off guard by new regulative developments, they proactively initiate low-carbon innovation activities. In the case of *Carbon2Chem* an expected rise in future ETS prices triggered this activity. Representatives of outdoor clothing companies such as *Tierra* expect a law on micro plastics (to fight pollution from plastic products) to be enacted in the near future.

4.3. Pulp & paper

The analysis of drivers and barriers of low-carbon innovations in the pulp & paper sector bases on the content analysis of the following three case studies and one innovation biography:

Case studies:

- *Äänekoski* bio-refinery (fossil-free pulp production: technical innovation on the resource and production side of paper production)
- *DuraSense* (innovative bio-composite, made of cellulose fibres, wood particles, and plastic; multi-purpose use)
- *Lime Kiln* conversion (operation of a 100% wood-powder-fired lime kiln)

Innovation biography:

- *LignoBoost* (extraction and cleaning of black lignin in the paper production process)

These case studies and the innovation biography exposed many different drivers and barriers which are summarised in Figure 4. The colour coding of the table is the same as for the other sectors.

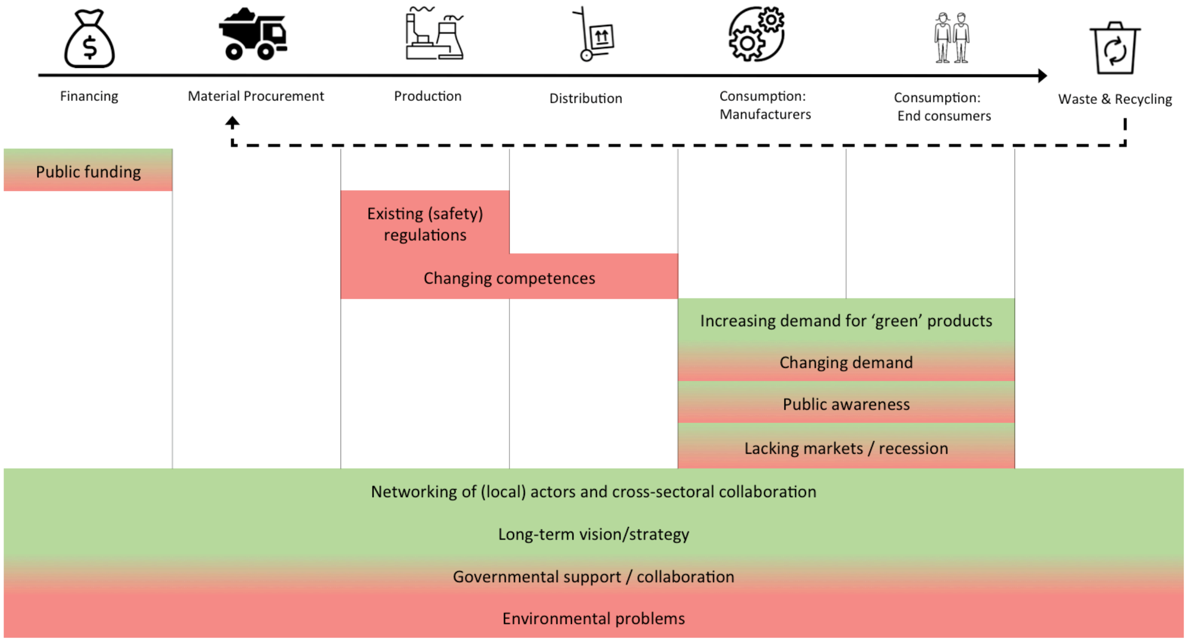


Figure 4: Drivers and barriers in the paper sector according to their influence on stages of the value chain
Key: Driver = green, barrier = red, potential driver or barrier = green to red

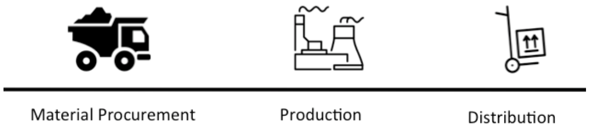
Considering their assignment to the different stages of the value chain, the identified drivers and barriers are described in further detail in the following. Specific examples from the analysed case studies and innovation biography are given for illustration purposes.

Financing

Public funding

Support by public funding mostly helps high-risk projects, e.g. innovative projects, due to access to more capital. Furthermore, public funding often involves better/other financing structures than private loans or investments. This can be a nodal point when it comes to the final investment decision for these innovations. *Äänekoski* received investment support from the Finnish state and Metsä Fibre, the initiating actor, had access to loans from European banks and funds. *LignoBoost* was developed in the framework of a research programme, which was led by RISE (then known as Innventia) and Valmet, a Finnish technology supplier. Innventia is a state-owned network of Swedish research institutes.

However, public funding may also affect a project negatively, due to long waiting times public funding may bring along. Moreover, there are often high regulatory standards that have to be considered when applying for public funding. These may affect other funding or the economic outcome of projects, e.g. in the case of *LignoBoost*. One of their customers ended up not investing in *LignoBoost* since the investment relied on public funding by the Swedish state, but they needed too much time to check if their selection process was fair or not.

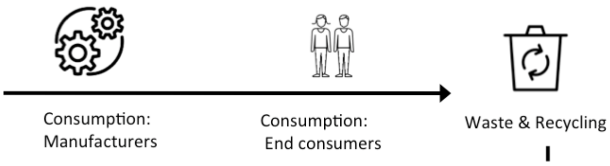


Existing (safety) regulations

Technology change brings along new risks. In the case of a change towards a wood-powered kiln, e.g., many safety regulations and explosion risks need to be considered. As dealing with and fulfilling the safety requirements is a complex process, it takes time until the process can run appropriately. In the *Lime Kiln* example mainly existing safety regulations constituted a hindrance since the company could not provide technical solutions and its employees lacked skills to implement those. Furthermore, NOx pollution regulations needed to be changed by the government, as it would have otherwise not been allowed to implement the innovative process.

Changing competences

Changes in the existing business model, new leadership or new work areas represent a big cultural change for employees. While some may see their chance in this development, others may be scared regarding the company's future. At Stora Enso, the initiating actor behind *DuraSense*, the innovation team needed to change to a new way of working. Furthermore, company leadership brought in new engineers with research competences to support further development of the mill. Quick decision-making was one of the main processes that needed to be introduced, because the employees were only used to improve existing processes and not to developing completely new ones.



Increasing demand for 'green' products

Demand for 'green' products rose in many different sectors. Due to more online shopping and globalisation, there is, e.g., an increasing demand for packaging which also affects the pulp & paper sector. Furthermore, some of the more sustainable plastic products could be produced as a by-product of paper mills (or – in the *DuraSense* case – in an old paper mill being reused). *DuraSense* focuses on 'green' plastics that are not used for packaging but, e.g., for plastic cutlery. The demand for this type of 'green' plastic is also growing.

Changing demand

Demand for paper changed significantly, in the case of printed paper mostly due to the increased use of online sources and e-newspapers. On the other hand, as the online retail market is growing packaging demand increases as well. The downturn in the market for printed paper forced companies owning large pulp mills specified on printed paper to consider new business models. *DuraSense*, e.g., made the decision to close the old pulp mills and produce a bio-composite. In the case of *Äänekoski*, also an old pulp mill, the decision was not as strict. They decided not to change the pulping process but instead make the best use of resulting by-products.

While on the one hand the industry benefitted from the change in demand, on the other hand many old Scandinavian pulp mills needed to close down. Market consolidation resulting from the reduced number of operating mills also diminishes the probability for innovations.

Public awareness

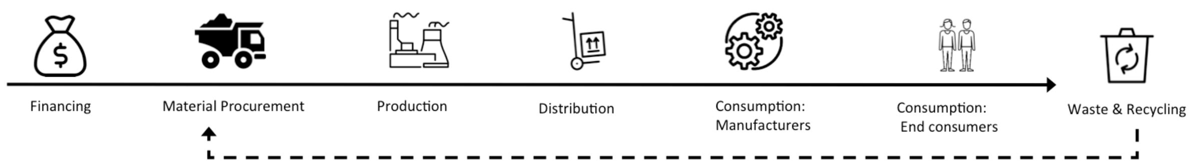
The interest of people in paper recycling and the usage of more environmentally friendly paper have always played an important role. However, due to the limits of recycling the sector needed to think of new ways to improve the sustainability of paper. While the wood-powered *Lime Kiln* is a good example of producing paper more environmentally friendly, there are many other examples for bio-fuelled kilns.

Nevertheless, consumers are often only aware of a certain side of a problem and maybe not even of the big picture. *DuraSense* as an alternative plastic which is mainly not used for packaging e.g. faces the problem that interest is not large for kitchen utensils and cutlery made of plastics.

Lacking markets/ recession

As mentioned beforehand, the downturn in the market for printed paper provided the possibility for some innovations to come up. Furthermore, it made people in the industry think about their future. The 2008-2009 recession was a driver for later innovations because it stopped earlier innovations which possibly would have been different in many aspects.

For *Lime Kiln*, the 2008-2009 recession was a also great barrier because it stopped expansion plans around the *Lime Kiln*.



Networking of (local) actors and cross-sectoral collaboration

In the pulp & paper sector, new collaborations represented a driver for low-carbon innovations as they helped companies to integrate new market knowledge. Moreover, collaborations with many smaller local companies improved the companies' social acceptance in the area. *Äänekoski* had partners/collaborators for many different purposes, e.g. for the waste water sludge, which was used for biogas production. In the case of *DuraSense,* the developer tested the material and its properties in various downstream applications and the team started working with local SMEs with expertise in plastics processing. In the *Lime Kiln* case, existing local alliances were also used and expanded.

Long-term vision/strategy

Some governments, especially in Scandinavia, support long-term visions and strategies of the industry by means of subsides or regulations. In the past, this represented a reliable instrument to guide sectors or industries towards a certain pathway. For example, *Äänekoski* expanded its product portfolio and chose a different route than most competitors. The *LignoBoost* innovation was developed in the early 2000s. Since 2013, two plants haven been employing the technology, so here the developers succeeded by following a long-term vision.

Governmental support / collaboration

Government grants helped some low-carbon innovations in the pulp & paper industry to grow and become economically viable. It can also become an important customer for innovative products.

However, government rules can also cause delay or problems for innovation projects. Stricter rules for forest management, e.g., could hamper the development of wood-based organic products. Furthermore, NOx-pollution regulations caused problems. Hence, government involvement may also cause process delays or even the failure of an innovative project.

Environmental problems

Due to a higher use of biofuels, demand for wood increases. As its availability is limited and it constitutes an important carbon sink, regulation aims at protecting the state of the wood and e.g. forbids its overuse. Such regulation has the potential to represent a barrier for innovations in the pulp and paper sector, as was the case with the NOx pollution regulation in the *Lime Kiln* case.

4.4. Meat & dairy

The analysis of drivers and barriers of low-carbon innovations in the meat & dairy sector bases on the content analysis of the following four case studies and three innovation biographies:

Case studies:

- *Friesland Campina* (Dutch dairy cooperative, has taken up 300 million € in investments to finance sustainable projects)
- *Green Protein Alliance* (multi-stakeholder partnership consisting of companies from the entire supply chain of plant protein products and various others partners)
- *Oatly* (company produces a variety of oat milk products for an international market, social innovation by re-framing the product for people with a sustainable lifestyle)
- *Cultured Meat* (produces in the laboratory by removing starter cells from an animal, rather disruptive innovations of actors coming from biotech start-ups and universities)

Innovation biographies:

- *Green Protein Alliance* (also analysed as a case study, see above)
- *Oatly* (also analysed as a case study, see above)
- *Ojah* (plant-based meat substitutes, development of a high-moisture-extrusion process for turning vegetable protein composition into meat-like structures)

These case studies and the innovation biographies exposed many different drivers and barriers which are summarised in Figure Figure 5. The colour coding of the table is the same as for the other sectors.

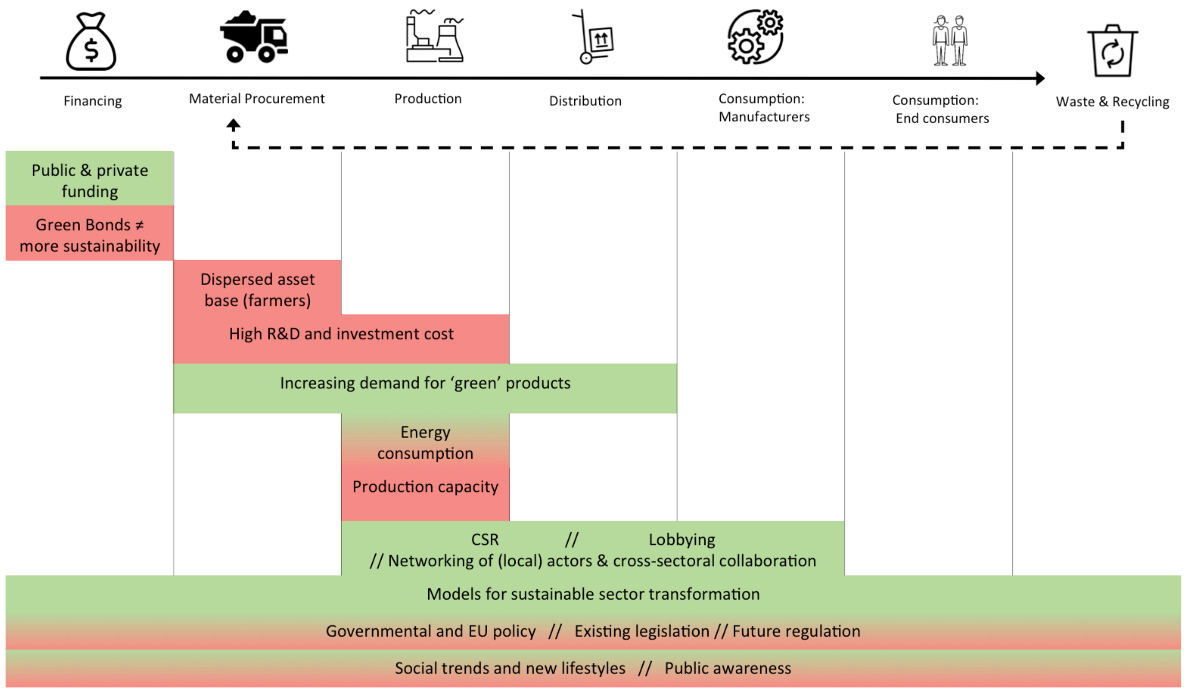


Figure 5: Drivers and **barriers in the meat and dairy sector according to their influence on stages of the value chain**
Key: Driver = green, barrier = red, potential driver or barrier = green to red

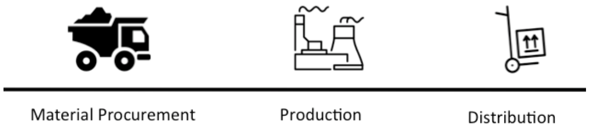
Public & private funding

According to the case studies examined, private funding at the beginning of product development and research into new products and start-ups is of particular importance for the Meat & Dairy sector. Here, investments are made on the basis of future value streams, as in the *Cultured Meat* case by wealthy private investors and venture capital companies. In the case of *Ojah* and *Oatly*, financing from regional investment agencies and venture capital funds was also used to set up the first production sites and new product lines. These financings were very successful for the companies in the early development phase and played a decisive role in product development and created the possibility of independent production.

In addition, national support programmes with sufficient budgets for the long-term development of the sectors, here in the case of the plant-based protein sector, also play an important role, as the *Green Protein Alliance* case made clear.

Green Bonds ≠ more sustainability

The recipients of "green" promissory notes can receive enormous sums for a variety of sustainable projects as part of a sustainable strategy, as the case of *Friesland Campina* illustrated. The general risk, however, is that the beneficiary will channel the funds provided into larger, on-going projects for pure refinancing, rather than providing additional funds for new sustainable projects. There needs to be a critical discussion about the use of these funds.



Dispersed asset base (farmers)

The internal structure of dairy and meat companies consists of two pillars: cooperatives (farmers) and companies (who buy milk and meat from farmers and, in the case of dairy companies, are often 100% owned by cooperatives). This means that at the production level, companies theoretically have a great influence on their upstream value chain, the farmers. Nevertheless, it remains difficult to make changes at the farm level of upstream value chains.

As the cases have shown, scattered ownership of farms (e.g. family businesses) makes it difficult to implement innovation activities in this way. It is easier for large factories to invest in their own projects, which are 100% owned by the company, as was made clear in the case of *Friesland Campina*. This makes it difficult to direct green financing in the agricultural sector towards the part of the value chain where most (70-80%) emissions occur, the farms. Results from the *Green Protein Alliance* case support this assumption, stating that the absence of companies from the entire value chain leads to stagnation of progress in protein transition.

High R&D and investment cost

The Meat & Dairy sector is characterised by a high number of well-known i.e. established and high-quality products, both in the meat and dairy sector. The replication of the enormous repertoire of products on the market means a high expenditure of time and money for research and development, as the cases *Cultured Meat* and *Oatly* show. In addition, as the *Ojah* and *Oatly* cases illustrate, high investment costs arise for the construction of new production facilities after the products have been developed.

Energy consumption

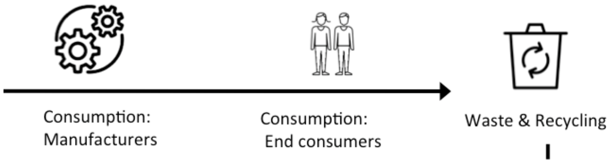
It is not clear with all innovations whether greenhouse gas reductions can also be achieved with the products. In the case of *Cultured Meat*, this is still difficult to assess, as farmed meat products are not yet commercially available. Cultivated meat could reduce CO_2-free greenhouse gas emissions and reduce land use. Energy consumption compared to meat production is unclear, while water consumption and ecotoxicity could be reduced.

Other companies, such as *Oatly*, advertise with their low-carbon qualities, which, together with other attributes such as taste, local value creation and a new lifestyle, shape sales tactics.

Production capacity

Innovations that establish themselves very quickly on the market often lead to capacity bottlenecks in production, for example at *Oatly*.

The realisation of *Oatly's* sustainable and targeted future growth also includes expansion into markets outside Europe - particularly the USA and China. This expansion of production capacities requires the time-consuming acquisition of new investors who can serve developments in a global market.



CSR

Niche innovations must first develop and establish their justification, their identity or their self-image for the company and the market. In the case of *Oatly*, it took years. After years of feeling unable to share its true values, which fundamentally challenge the dairy industry, *Oatly* decided to rise to the challenge and do just that. Success proved *Oatly* right. Partnerships such as *Green Protein Alliance* also show that an overarching strategy to develop a sector can also lead to greater internal identification with a company's reorientation or new product lines.

Lobbying

Through targeted public relations work, lobbying is also carried out in companies. Rankings, awards and other distinctions are a suitable means for this. In the case of *Ojah* there were some awards that had a positive effect on the company (first place in the SME Innovation Top 100 in the Netherlands, winner of the Oranje Handelsmissiepakket Award). As a result, *Ojah* expanded internationally.

In the case of *Oatly*, a legal proceeding against the company were also used as lobbying. *Oatly's* legal proceeding was communicated to the public to demonstrate the superiority of the traditional dairy industry. In addition, *Oatly* founded his own lobby organisation.

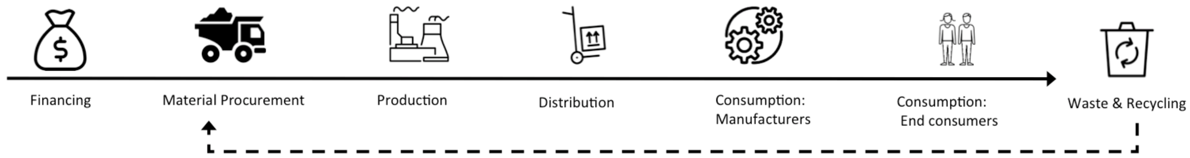
Oatly uses the concept of 'the Oatly way' to make decarbonisation legible, in graphical illustrations they show how grains go directly into milk instead of passing through a cow. Although simplified (cows grazing is not mentioned) – the message is effective.

Networking of (local) actors & cross-sectoral collaboration

The importance of networking proved to be very important in the cases considered.

Access to expertise and facilities enabled the innovators to continue their work in the case of *Ojah*. For example, working with a first customer, a vegetarian butcher, proved crucial to *Ojah's* development. In addition, *Ojah* organised the first industry association, Het Planeet, for producers of meat substitutes in the Netherlands. The idea behind Het Planeet was to work together to increase the market share of vegetable meat substitutes. Several companies became members of Het Planeet and since then several knowledge and product developments have been built up. Het Planeet became a founding member of *Green Protein Alliance* in 2016. As this case illustrated, a strong plant protein network is essential to understand the industries demand challenges and limited reach in influencing consumer behaviour.

One of the most important perceived successes of the *Green Protein Alliance* has been that the initiators have succeeded in establishing a partnership to promote the consumption of plant proteins between the major players in the agri-food sector. The constellation of members and partners in the *Green Protein Alliance case* was perceived as a central factor in influencing protein consumption. All members and partners play a special role in achieving the goal of 50:50 vegetable 50:50 (vegetable:animal) protein intake by 2025. In the course of the implementation, the *Green Protein Alliance* also succeeded in gaining new members such as Unilever, one of the largest food companies in the world, and Jumbo, one of the largest trading companies in the Netherlands. As a result, the potential impact of *Green Protein Alliance* projects is increasing.



Models for sustainable sector transformation

Models for sustainable sector transformations, as formulated in the *Green Protein Alliance* case, serve to structure the sector. Public and private actors must work together towards a coordinated, tailor-made plan. The market transformation models were well received by the initiators, *Green Protein Alliance* members and partners. They have thus made a significant contribution to making the potential of the initiative readable and to facilitating the establishment of the *Green Protein Alliance*.

A model of sustainable sector transformation could also prove meaningful in the case of *Cultured Meat*. *Cultured Meat* could contribute as a primary tool to tackle climate change in the meat sector and also contribute to lower antibiotic use, public health and sustainable resource management, avoiding the need for consumption reductions and major nutritional changes.

In such narratives, which are at the beginning of models for sustainable sector transformation, meat and protein-based cultured dairy products already serve as the main means to address climate change in the meat and dairy sectors.

Governmental and EU policy

In the dairy sector, national political decisions in particular have had a beneficial effect. In 2013, for example, the Dutch Duurzaamdoor programme was established. Duurzaamdoor aimed to accelerate the development of an environmentally friendly economy in several sectors, including the food sector. The protein transition reappeared on a larger political agenda and was selected as one of the key issues. The development of the *Green Protein Alliance* and the Green Growth Plan received considerable political support from then Foreign Minister Martijn Van Dam. He supported the Ministry's participation in the *Green Protein Alliance* and enabled the promotion of plant protein innovation.

Existing legislation

On the demand side, there is an almost complete absence of strict regulations for the consumption of emission-intensive foodstuffs, and the dairy sector in particular is largely regulated by hybrid and private governance initiatives. Regulatory obstacles still exist for the plant-based products sector (regulation on organic products that differ from milk to plant milk, subsidy systems that may not call their products "milk"), as the *Oatly* case made clear.

Another important aspect is that it appears that regulatory barriers can be turned into stepping stones if they are presented as unfair in society, since the actor concerned is considered credible as a rebel/minor player (*Oatly*).

Future regulation

Low-carbon innovations in the meat and dairy sector in Europe are largely dependent on an appropriate common agricultural policy revision and a food and health regulatory structure that can promote dietary change, novel foods and alternative agricultural and meat production methods. It is essential that policies are developed within a holistic perspective and identify potential unintended side effects in line with the precautionary principle.

In the case of *Friesland Campina*, it became clear that the dairy industry expected the introduction of stricter regulation in the future to ensure that the agricultural sector contributes to national CO_2 reduction targets. The company is trying to demonstrate through its emission reductions to date how much has already been reduced and hopes that the rules for the dairy sector will be less stringent.

There is still great potential for reducing meat and milk consumption. However, due to uncertainties over the impact of demand-side food regulations, such as excise taxes on food, and strong opposition from industry, governments are reluctant to introduce demand-side regulatory measures that would regulate consumption.

The introduction of new products is often not yet regulated by law, and in the *Cultured Meat* case it is not yet possible to assess whether a lack of legal framework will have an impact on the further development of innovation.

Social trends and new lifestyles

All the cases considered here in the meat & dairy sectors are based on a change in social trends that justify a new lifestyle or megatrend. The *Oatly* brand for example was not established as a threat to the traditional dairy market, but as a niche market responding to a new lifestyle. The discussion on the impact of farm animals on climate change, stimulated by various reports, popular culture and the vegan movement, enabled the vision of a 'post-milk generation'.

In the absence of social trends, however, it will be difficult to replace established products on the market with new ones.

Public awareness

Increased awareness of the negative environmental impacts of meat and milk production has basically led to increased public pressure and political attention. Social practices and habits change particularly quickly and stably if the products do not produce any discernible disadvantages or setbacks for the consumer. For example, the creation of *Ojah* has helped to increase the variety and quality of meat substitutes at the market. The company is thus serving a growing social trend towards sustainable lifestyles and at the same time increasing the acceptance of its own products. Such internal company events coincided with an increased awareness of the negative environmental impact of meat and milk production and a growing cultural acceptance of meat and milk alternatives. (*Oatly, Ojah*).

The global increase in meat consumption is increasingly viewed negatively by the public due to greenhouse gas emissions and animal welfare. Such a development is expected as a basic prerequisite for the introduction of *Cultured Meat* production.

The *Green Protein Alliance* case, on the other hand, has shown that the growth of vegetable protein consumption faces many challenges, including a particularly low level of consumer acceptance (GPA-SIT).

5. Cross-sectoral drivers and barriers of low-carbon innovation

5.1. Results comparative structured analysis

After identifying sector-specific drivers and barriers for low-carbon innovations (see Chapter 4), the results for the steel, plastic, pulp and paper and meat and dairy industry were compared. The aim was to identify which drivers and barriers play an important role not only in one sector, but also across sectoral boundaries. In the following, identified cross-sectoral drivers and barriers are described and examples from different sectors are given.

The analysis of cross-sectoral drivers and barriers of low-carbon innovations bases on the content analysis of data sources described in Chapter 3. These comprise 18 case studies (from Work Package 3.3/overview in Deliverable 3.3), five innovation biographies (WP 2.3/D2.7) and 122 innovations from the decarbonisation innovation database (WP 2.2/D2.1).

The following Figure **6** visualises the identified cross-sectoral drivers and barriers which triggered or hindered decarbonisation efforts in the steel, plastics, pulp and paper and meat and dairy sectors. As in the previous chapter, drivers are displayed in green boxes, barriers in red boxes and potential ambiguous influencing factors in boxes turning from green to red. Each factor is again assigned to that stage of the plastics value chain on which it exerts the biggest influence. If this is true for several stages, the box extends to the respective steps up to the whole value chain.

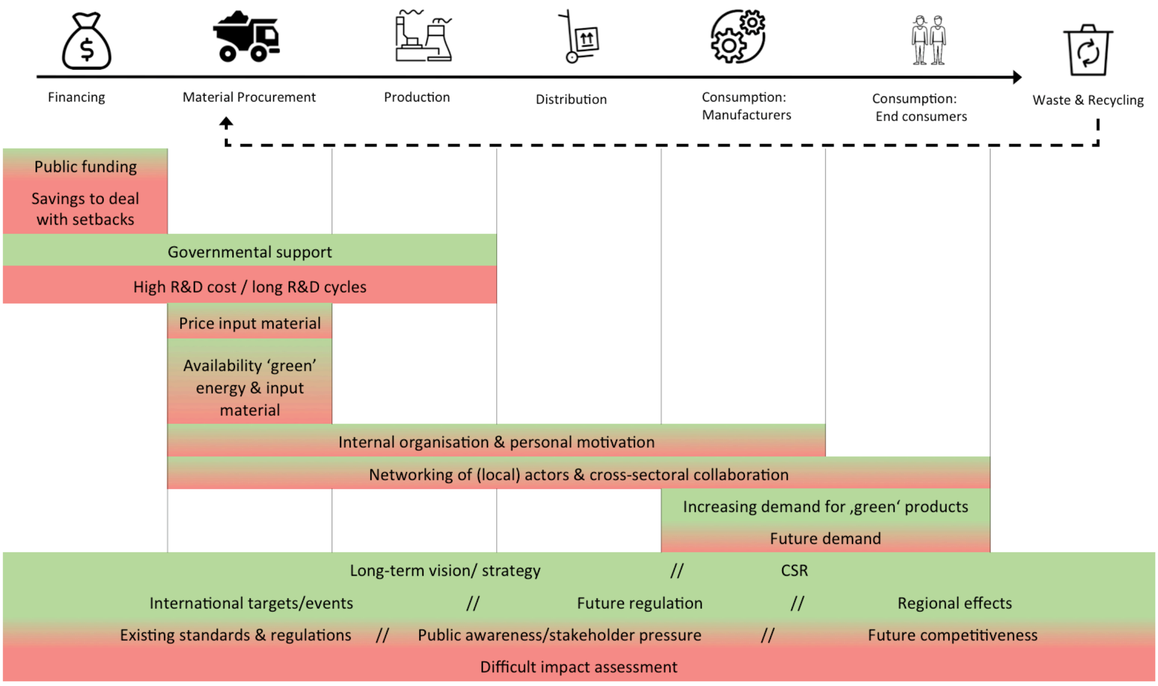


Figure 6: Cross-sectoral drivers and barriers according to their influence on stages of the value chain
Key: Driver = green, barrier = red, potential driver or barrier = green to red

The occurrence of the drivers and barriers from Figure **6** in the different sectors is explained more thoroughly in the following. For more detailed descriptions of particular factors see Chapter 4.

Public funding

Potential financial support from public entities for innovation processes is mostly considered helpful or even crucial (e.g. *HYBRIT* (steel), *Äänekoski* (pulp & paper), meat and dairy cases). However, there were critical voices from the plastics and paper industry. On the one hand, in interviews with *Enerkem* Rotterdam representatives (plastics) public grants were considered too small to actually help mitigate the business risk of the innovation process.

On the other hand, in the *LignoBoost* case (pulp & paper) there was so much back and forth regarding potential public funding that it prevented a producer from investing in the technology for their plant.

Governmental support

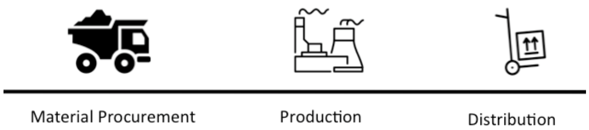
Besides direct financial grants and subsidies, public entities often also provide support for innovative projects by other means. In the case of the *Carbon2Chem* project (steel/plastics), e.g., the state government brought the companies and research institutions together which later formed the project consortium. *LignoBoost* (pulp &paper) was partly developed by RISE (then known as Innventia), which is a network of many different Swedish research and technology organisations, owned by the Swedish government.

Savings to deal with setbacks

A lack of equity capital is a factor which prevents the initiation of low-carbon innovation processes in all sectors. This is due to the fact that, as mentioned in the case study on the outdoor clothing company *Tierra* (plastics), many smaller companies do not have sufficient financial reserves to deal with setbacks in an innovation process which naturally involves a lot of trial and error.

High R&D cost/ long R&D cycles

Especially in the steel but also in other industries, R&D processes often imply (relatively) high cost of development and long phases of insecurity. This results in a significant financial risk. Although total cost for an innovative steel technology might be higher than for a meat and dairy innovation, it could pose a similar financial risk to a single farmer possessing significantly less equity capital than a big steel company. As mentioned, e.g., during interviews for the *HYBRIT* (steel), *Enerkem* (plastics), *Oatly* (dairy) and *Cultured meat* (meat) case studies, these circumstances represent a barrier to low-carbon innovations as they prevent investments by some actors.



Price input materials

As prices of input materials strongly affect the economics of production, a price increase in this area can spark R&D efforts for alternative materials in all of the examined sectors. This happened e.g. with research on waste as a fuel source (which ultimately led to *Enerkem*'s proprietary technology (plastics sector), among others) when oil prices increased sharply in the 1970s.

On the other hand, if the low-carbon alternative is more expensive than the conventional option, this can be prohibitive. Outdoor clothing company *Tierra* (plastics), e.g., overcame the issue of higher input material prices of bio-based versus fossil-based plastics only by changes in design (e.g. jackets with fewer pockets) which resulted in a lower use of fabric.

Availability 'green' energy & input material

A key issue for low-carbon innovations in all sectors is the availability of sustainable energy and input material. The possibility to obtain sufficient renewable electricity, e.g., was a major driver for the initiation of the *HYBRIT* project (steel). The *Enerkem* Rotterdam (plastics) consortium benefits from the fact that already a lot of waste is being transshipped at the Port of Rotterdam. Furthermore, waste is a comparatively cheap resource which is readily available in many locations.

The opposite is true, e.g., for bio-based fabrics. *Tierra* (plastics) and other small producers of outdoor clothing were only able to obtain bio-based fabrics when they jointly ordered larger volumes and thereby managed to achieve critical order quantities.

Internal organisation & personal motivation

If highly motivated people who strive for a low-carbon transition get together, they can drive change from within a company. This happened, e.g., in the case of *Tierra* (plastics) where employees had a stated goal of addressing their company's products' dependence on fossil-based fabrics. The restructuring of internal processes by StoraEnso in the *DuraSense* case shows that organisational change within a company can help moving innovation projects forward.

In contrast, unfavourable company-internal organisation (e.g. between different business units) can be a barrier to the initiation or implementation of innovation processes in all sectors.

Networking of (local) actors & cross-sectoral collaboration

The majority of analysed innovation cases benefitted from formal or informal networking activities and collaboration with (local) actors along the value chain or from different sectors. One example is the *Green Protein Alliance* (GPA, meat) where many companies joined forces to change the ratio of protein consumption in the Netherlands to 50:50 protein (plant:animal) by 2025. Another example for networking of local actors is *Äänekoski*. They have partners for many different purposes, e.g. for the waste water sludge. This helped them for the development of the plant and it also helped the region, because they have mostly small regional partners.

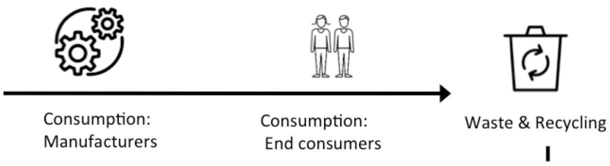
However, especially regarding joint R&D projects the question of property rights can be a sensitive issue. It can lead project partners to proceed with caution, potentially slowing down innovation, making it less effective or even do not cooperate at all. While the *Carbon2Chem* consortium (steel/plastics) was established successfully, project partners act with a general caution.

Workshop feedback

The topic of **cross-sectoral collaboration** sparked a conversation about the dynamics of such projects, the distribution of power, and the threat of lock-in. From a chemicals point of view, a project like *Carbon2Chem* may put the industry at the mercy of the steel industry: Will these types of

CCU innovations merely be an interim solution? If hydrogen is the steel industry's proclaimed long-term goal, will they eventually tear down all their blast furnaces, leaving the chemical industry without a carbon source? Or from a different perspective: Will large scale CCU projects such as these create a lock-in effect, preventing the steel industry from investing in newer, fossil-free alternatives like H-DR, thus turning collaboration into a barrier to deep decarbonisation?

While discussing aspects of collaboration, a lack of **collaboration along the value chain** – from basic materials to recycling – was also identified by participants as a barrier to tackle larger issues in an innovative manner. A recycler, for example, may have pertinent information that a manufacturer is lacking, and vice versa. Acting individually, companies may be able to solve smaller problems, but not larger, systemic issues in order to progress toward a zero-carbon industry.



Increasing demand for 'green' products

Across all sectors interviewees noted that higher awareness of environmental issues resulted in increasing demand for more plant-based, fossil-free products and production processes. Hence, not only end consumers change their behaviour but also manufacturers are including more sustainable practices in their procurement strategies. The range spans from alternatives for meat products e.g. fuelling cultured meat production to 'greener' packaging options produced by *Lime Kiln* (pulp & paper).

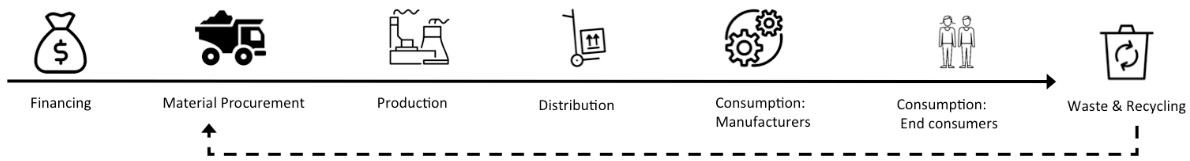
Future demand

In big cross-industrial projects like *Carbon2Chem* (steel/plastics) or *Enerkem* (plastics), the future buyer of the produced chemicals is already part of the consortium. This mitigates the economic risk of unsure future product demand and constitutes a driver of innovative R&D projects.

In the opposite case, the *Tierra* company (plastics) was unsure whether there would be consumer demand for its bio-based jacket. Furthermore in the meat & dairy sector most companies are not sure whether their demand depends on social trends or is representative for the future demand. Such considerations can hamper innovation activities in all sectors.

Workshop feedback

The discussion of **future demand** and downstream **CSR** as drivers for innovation raised the question of scale. How big a player does a downstream manufacturer have to be to influence, for instance, the production and availability of low-carbon steel? A large player (e.g. a car manufacturer) announcing CO_2 neutral products (e.g. a zero-carbon car) is likely to elicit reactions from all its suppliers, including steelmakers. A smaller player will not be able to create such momentum. In some instances, smaller players come together to reach a scale of demand that is profitable for the supplier to meet (e.g. *Tierra*). However, this is likely much more difficult to achieve for something involving a whole new production process (e.g. hydrogen direct reduction). On top of this, a lack of supply chain transparency complicates the issue, as many downstream players receive products sourced from a range of different suppliers, making it difficult to pinpoint where exactly to put the pressure.



International targets/events

The Paris Agreement is stated to have been a 'wake-up call' which prompted various industry players to prioritise low-carbon R&D. Corresponding statements were made, e.g., by *Carbon2Chem* consortium members (steel/plastics) as well as *Tierra* employees (plastics). Both initiated their low-carbon projects after the event.

Future regulation

There are innovations across different industry sectors which are intended to pre-empt expected future regulation. This applies, e.g., to *Friesland Campina* who expect stricter dairy farming regulation. Similarly, outdoor clothing companies like *Tierra* (plastics) anticipate an incoming law on micro plastics (to fight pollution from plastic products).

Regional effects

In most of the case studies, certain regional effects fostered the development of low-carbon innovations by resident companies. In the case of *HYBRIT*, high specialisation and almost no competition between steelmakers favours a joint undertaking like the Swedish steel association's vision. Moreover, Sweden has a good low-carbon electricity supply and iron ore production. The presence of potential consortium partners at the Port of Rotterdam as well as logistical advantages linke to the port contributed to the initiation of the *Enerkem* Rotterdam initiative (plastics).

Existing standards & regulations

If it aims at achieving a low-carbon transition, existing regulation can foster innovative projects. *Enerkem* Rotterdam (plastics), e.g., was also established due to EU legislation on biofuels which requires an increasing share of fuels to originate from renewable energy sources including waste.

In contrast, lax standards or non-existent regulation are sometimes stated to be a barrier. A lack of follow-through on regulation e.g. made way for voluntary certification in the *BREEAM* case (steel), which tends to be less strict and effective. According to owners of *waste-free grocery stores* (plastics), the lack of regulation on sustainability of food packaging rather discourages investments in their business. Safety regulations have been an issue for the *Lime kiln* (pulp & paper) innovation, mainly the technical problems that the regulations brought up were more difficult to face.

Workshop feedback

Focus group participants argued that **regulation** is – and should be – one of the main drivers, but needs to be well thought through in order to have the desired effect. Stakeholders and experts should be consulted to ensure that regulation considers pertinent scientific and technological knowledge. Participants conceded that it is not always easy to give straightforward advice, as innovation projects often are not advanced enough to allow any sort of well-grounded prognosis for future scenarios. One question that was thus raised concerns the trade-off between speed and information when it comes to political decision-making. The right balance between the two needs to be evaluated on a case-to-case basis: Generally, participants agree, it is important to remain technology-open. In some cases, however, it was argued that it may be preferable to 'just make a decision' quickly, in order to move innovation along at the necessary speed. Long-term emissions reduction targets need to be taken into consideration when making decisions on regulation now, as many of these innovations will require decades to be rolled out and produce the desired effect on GHG emissions. The same considerations need to be applied when deciding whether to focus solely on long-term solutions or whether the promise of speedy reductions makes interim solutions worth promoting.

One regulatory instrument that was discussed quite extensively is **carbon pricing**. Different options for implementation (carbon tax, emissions trading) and its scale (national vs. European vs. global CO_2 markets, options for a border adjustment tax) were raised repeatedly throughout the day. The uncertainty of the future development of CO_2 pricing makes for unstable conditions for investment, and is thus currently seen as a barrier. The price of low-carbon materials will not be competitive unless the right framework conditions are established. A comprehensive and well thought-out carbon-pricing concept could therefore be an important driver for future low-carbon innovation.

Public awareness/stakeholder pressure

In many case studies, interviewees stated that rising public awareness of environmental issues represented an important driver for innovation activities. For example, pollution by plastics (marine litter, microplastics) is very high on the public agenda at the moment and an important factor for the opening and success of *waste-free grocery stores* (plastics).

Industry insiders, however, also complain about a lack of public awareness of factors which also have the potential to drive low-carbon innovations. Among these are the properties of bioplastics (*DuraSense*, pulp & paper), certain health and sustainability aspects of food (*Oatly, Cultured Meat and Green Protein Alliance*, meat & dairy) and the fossil origins of clothing fabrics (*Tierra*, plastics).

Workshop feedback

Focus group participants discussed the topic of public perception and **awareness** quite extensively. On the one hand, it can be a powerful way to drive change (e.g. the contribution of consumer awareness to restrictions and bans of plastic bags). On the other hand, consumer attitudes are hard to identify as purchase decisions are influenced by a variety of different factors (most importantly, cost). Furthermore, there is a lack of coherent information, or oftentimes plain misinformation, on the climate and environmental impact of certain products and packagings (e.g. end-of-life implications of bio-plastics). A lack of supply-chain transparency often contributes to this. Finally, creating awareness can be hampered by information overload.

Future competitiveness

Especially companies which currently heavily depend on fossil fuels fear for their long-term economic competitiveness and therefore engage in the strategic development of innovative low-carbon business models. Firms at the chemical cluster of the Port of Rotterdam (*Enerkem* case, plastics) as well as steel companies (*Carbon2Chem* case) are among these actors.

However, R&D of cleaner products and technologies is often costly and their implementation more expensive compared to conventional procedures. As a result, other companies refrain from such activities due to concerns about their medium-term global competitiveness.

Difficult impact assessment

Companies in different sectors refrain from innovation processes if it is difficult to determine in how far an alternative product or process is actually more sustainable than the (conventional) alternative. If different low-carbon options are on the table, some firms rather prefer to wait and initiate R&D processes only later when the options' potential impacts have been researched in further detail. In the case of voluntary certification schemes for materials in buildings (*BREEAM*, steel), e.g., embodied life cycle emissions of buildings are very difficult to measure as data is complex and can be lacking in quality. The actual environmental impact of bio-plastics (compared to recycled plastics) is also still a topic of debate according to *Tierra* representatives (plastics).

Corporate social responsibility

In the case of many innovative R&D projects, CSR constitutes one of several drivers for low-carbon innovations. In view of a growing awareness of environmental issues, many companies aim at showcasing their climate protection efforts to the public. The Swedish steel industry, e.g., has a goal to shed its reputation as being Sweden's top emitter by becoming part of the solution, rather than remaining part of the problem. The *HYBRIT* project is a step in that direction. *Waste-free grocery stores* help reducing the demand for plastic packaging production and also littering. Partnerships such as *Green Protein Alliance* show that an overarching strategy can also lead to greater internal identification with a company's reorientation or new product lines.

Long-term vision/strategy

If companies follow a long-term strategy, this seems to be a success factor for the development of low-carbon innovations. As they do not have to concentrate on near-term profits, chances are higher that barriers can be endured and overcome. This was e.g. true for the dedicated owners of *Tierra* and also to the Canadian founder of *Enerkem* who aimed at solving the problem of waste disposal and achieve low-carbon transportation. Company or industry-wide long-term visions, such as the Swedish Steel Association's vision to contribute only positively to society, can foster big long-term R&D initiatives like *HYBRIT*.

5.2. Results finance case studies *Fossil-free churches* and *Triodos*

As mentioned in Chapter 2, the two finance case studies *Fossil-free churches* and *Triodos* differ from the other 16 case studies in so far as they cannot be attributed to one of the four REINVENT sectors steel, plastics, pulp & paper and meat & dairy. Instead, they cut across these sectors as financing itself can constitute a driver or barrier for decarbonisation innovations in the four sectors.

However, the results from the *Fossil-free churches* and *Triodos* case studies should be taken into account for the analysis in this work package. Therefore, they were examined for factors representing potential cross-sectoral drivers and barriers of financing low-carbon projects. These two cases are examples of the variety of ways in which low-carbon finance is taking shape. While some of the results discussed here are indicative of cross-finance trends, others are specific to particular types of finance (such as bank lending or institutional investment). The results of this analysis are outlined in the following.

Overall, it seems that the financial sector's potential for driving low-carbon innovations in the REINVENT sectors has so far hardly been exploited. This is true for investing in low-carbon activities as well as divesting from high-carbon business models. So far, small decarbonisation activities requiring comparatively little financing have been the ones most likely to receive funding by ethical banks for their 'green' projects.

Drivers from within the financial sector which foster low-carbon innovations in the steel, plastics, pulp and paper and meat and dairy sector are relatively rare. The factors which have been identified are rather recent developments which bear the potential to become very meaningful in the future. (This is probably also the reason why they were not mentioned by interviewees from other case studies).

As in the other four sectors, an underlying general driver is the growing awareness of environmental issues. This leads to changes in different areas:

- For investment finance: Investment managers and pension trustees have a statutory duty to act in the best interest of those whose money they manage. While this has usually been interpreted as a duty to maximise financial return, it is increasingly considered to also include environmental, social and governance factors.
- Furthermore, there is a growing (voluntary) drive among institutional investors to align their investment portfolios with a 2 degree scenario. (This, however, requires new forms of knowledge and techniques to be in place, in order to determine whether companies align with such a scenario or not.)
- Also among private consumers there is a growing interest in making sure their money makes a positive, ethical impact, which is driving changes in both the banking and investment sector.

Altogether, this could result in a larger amount of capital being provided for financing of low-carbon innovations. As of yet, such a growing demand for sustainable investment alternatives has been noticed. There even is some evidence to suggest that ethical banks have more money coming in than they can lend out to/invest in sustainable businesses.

Currently, there is a variety of **barriers** in place which prevent increased funding of low-carbon projects. Some barriers - especially in bank lending - even contribute to a situation in which increased funding for sustainable investments would not necessarily result in more financing of low-carbon projects.

Many of the barriers are systemic, i.e. they are closely related to the internal capacity of the banks offering ‚green' investment products, the regulatory environment and/or to the nature of investing:

Internal capacity of banks:

- In some cases supply of sustainable investment alternatives constitutes a barrier to low-carbon financing. As ethical banks are often small, they might lack the capacity or expertise to offer more complex financial products. This limits their use for institutional investors, who will generally seek to invest large sums of money, and thus also reduces the amount of money available to invest in 'green' companies and projects.
- The small size of many ethical banks also leads to the fact that ethical lending usually involves comparatively small sums of money (compared to equity investments). Therefore, large innovative low-carbon projects from the steel and pulp and paper sector are less likely to receive 'green' funding than smaller companies, e.g. producers of organic food or alternative plastics.

Regulatory environment:

- Moreover, complex regulations inhibit that ethical banks offer investment products to private investors as mainstream banks do.
- Another barrier also mentioned in other case studies is a widespread lack of regulation supporting the transition towards a low-carbon economy. Regarding investment financing, this

becomes apparent as the need to change financial practices is often not included in low-carbon strategies. For example, although the Swedish Government declared they wanted to be the first fossil free welfare state, they did not include investment by national pension funds in their strategy. In general, political faith appears to be placed in self-regulating market pressures to shift patterns of bank lending away from high-carbon sectors. This is supported by the fact that mandatory climate risk disclosure is not yet a reality in most of the EU. However, an increasing number of financial institutions, including some banks, have signed up for voluntary climate risk disclosure agreements.

Nature of investing:

- In addition to that, the need to spread investment risk makes it difficult to only focus on clear 'green' alternatives.
- The complexity of the investment chain makes it difficult for investors to differentiate between ‚good' (low-carbon) and ‚bad' (fossil-based) approaches. While some investors have their own decision procedures, particularly for smaller investors the complexity of the investment chain turns the investment decision into a challenging process. Recent initiatives such as the ClimateAction100+, TPI and Science Based Targets aim at helping investors to assess the climate impact of their investments. However, it is still too early to tell if these instruments will be successful in driving decarbonisation.
- In addition, so far many investors consider carbon differently depending on its material properties and not necessarily in a careful assessment of emissions. The United Reformed Church, e.g., suggests that due to a lack of commercial-scale low-carbon alternatives, the use of fossil fuels in steelmaking and plastics production can be viewed differently from the combustion of fossil fuels for energy. Hence, companies initiating low-carbon projects in these sectors might not be preferred by investors over those employing conventional technologies.

There is also a geographical aspect which could play a role for continued investments in fossil-based business models:

- Due to the presence of high-carbon industries in some countries, investors are concerned about the potential socio-economic impacts divestment from these companies could have (e.g. more opposition to divestment in the Church of Scotland, an important site of the oil industry).

In sum, there is some evidence that the world of finance is changing, with an increased interest for green or low-carbon forms of lending and equity investment, driven by both voluntary initiatives, and more recently, a changing regulatory environment (at least in Europe). However, the big question is to what extent this will translate in additional money flowing towards low-carbon innovation in the REINVENT sectors. So far much of the discussion within the financial sector has focused on either divesting from fossil fuel companies or investing in green technologies, particularly renewable energy. These cases show there is some way to go for the REINVENT sectors to demonstrate their (potential) low-carbon qualities in order to attract these new streams of 'green' finance.

As these results cut across the four REINVENT sectors, they were not presented or discussed separately at the workshop in Düsseldorf on 16th September 2019. Instead, issues of financing found entry into the workshop debates where appropriate.

6. The 2050 perspective

As explained in Chapter 2.3, in the afternoon session of the workshop in Düsseldorf participants were split into three focus groups. These were conceptualised to shift the historical/present perspective provided by the meta-analysis of the case studies, innovation biographies and innovation database to a future perspective, exploring important influencing factors for reaching industrial decarbonisation by 2050. The relatively open discussions that ensued highlighted opportunities to drive change as well as barriers that will have to be overcome, emphasised key areas of decision making and raised essential questions for future research. These issues could thus constitute a starting point for the design and set up of strategies and policies to facilitate future innovations in the considered sectors (as an input for WP6 but also in general).

6.1. Focus Group I: Changing demand side and lifestyles

Focus Group I discussed how individual consumer demand change can be fostered, and who the relevant agents of change are, in order to contribute to decarbonising industry by 2050. The consensus was that demand-led action would play an important role, seeing as it often precedes regulatory or industry innovation.

Building on the discussion of 'public awareness' as a cross-sectoral driver, the focus group based their understanding of consumer demand change on a three-step process, according to which it is achieved by:

(1) creating awareness through education and information,
(2) creating stable attitudes (e.g. through storylines that connect to consumers) and
(3) translating these into habits.

Subsequently, different options for how to approach and think about demand change in the future were discussed and questions for further research raised, including a focus on

- people's desires *(How can 'green products' be made desirable?)*
- consumers' existing routines and practices *(How can low-carbon choices be integrated into these?)*
- differentiating between occasional and regular purchase decisions *(Which type of purchase decision is easier to change – a house or a carton of milk? Which is more impactful?)*
- products' low-carbon qualities *(How can they be made visible?)*

Focus group participants also discussed the role that different agents of change can play in enabling future demand change. It was concluded that **industry** can drive demand change mainly through creating new narratives. The main barrier for industry to overcome lies in a lack of trust of consumers in industry's claims. In terms of the role of **regulation**, participants discussed a trend for a reduced appetite for global regulation. The question was raised of how regulation at lower levels can stimulate demand in the future, without creating overspills into other regions. In terms of **civil society action**, a barrier to overcome lies in a potential lack of permanence. In debating how a reversal of civil society action through future trends may be avoided, a proposed solution was to create interaction between civil society and industry *(civil society action leading to product innovation)* as well as between civil society and regulation *(civil society action leading to the implementation of new laws and regulations)*. The question of how to foster these types of interactions was deemed crucial for ensuring that consumer demand change contributes to decarbonising the industrial sector by 2050.

6.2. Focus Group II: New industrial cooperations and a change of traditional sector views

Looking at 2050, Focus Group II discussed the necessity for a total socio-industrial reorganisation of society, rather than just transitions in specific sectors. Participants expect a shift in the focus of decarbonisation activities towards materials: For example, once cars run on renewable electricity, most of their environmental impact will be in the materials. The same goes for buildings: Once they can be heated in an energy-efficient and carbon-neutral way, focus will shift to the emissions embodied in the building materials. There will be a lot of opportunity for those industrial actors who already have solutions at the ready.

One of the first obvious steps will be to reduce the overuse of materials, such as steel and concrete in buildings. Questions of dematerialisation were raised. Developing working business models for this was identified as a serious challenge: Reducing the production volume while increasing the value of the products (e.g. through longer product lifetimes, reusability), thus being able to sell them at higher prices, is one strategy that was debated. Enabling such a shift will be central to decarbonisation through reduced material use and questions of how it can be achieved will need to be addressed by future research.

At the same time, supply chains are expected to become shorter, and value chains more circular. This raised an important question: The drivers and barriers derived from the project's case studies and biographies reflect the linearity of the analysed innovations. Can they be transferred to innovation for a circular economy? Which additional drivers and barriers will be of importance? Among others, issues of design for reuse/disassembly/recycling, extending product lifetimes and tracing materials were raised.

Besides length and circularity, value chains may also become more integrated across traditional sectoral boundaries, particularly as bio-based materials gain importance (e.g. integration of chemicals/plastics/biomass/paper). A key barrier will be the scarcity of biomass in a fossil-free industrial system. Question raised included: How will basic materials industries transition to a completely fossil-free system? How will scarce resources be allocated? How will power dynamics between different sectors shift?

Another key barrier to overcome will be the danger of lock-in through industrial symbiosis during a period of transition. The group debated whether projects such as Carbon2Chem would have carbon lock-in effects for both the steel and the chemical industry, or whether it would prove to be a stepping stone to something else (i.e. a technology that opens doors to non-fossil carbon feedstock in the chemical industry). Questions of how to ensure the necessary flexibility to achieve the latter rather than the former were raised.

6.3. Focus Group III: Framework conditions

Focus Group III on 'Framework conditions – economic incentives, government regulation and technical/infrastructural standards' discussed the leading question: By 2050, what will have been done in regard to political and infrastructural framework conditions to achieve the decarbonisation goals in resource-intensive sectors?

One of the first conclusions drawn from the group's discussion is the need for the political system to become more technology-open and make 'greener' solutions more (economically) attractive.

Currently, it rather incentivises and stabilises yesterday's production systems; a first necessary step will be to stop all economic incentives for the extraction and use of fossil fuels. What will be needed in general are regulations and policies that are flexible enough to make decisions now and adjust them according to future developments. The group raised questions on the merits and downsides of taxing (de-incentivising) vs. subsidising (incentivising), and public procurement as an instrument to 'kick-start' new markets. There is no one-size-fits-all solution: These instruments will need to be evaluated on a case-by-case basis, and re-evaluated on a regular basis.

Looking at 2050, group consensus was that a global CO_2 price on the carbon content of all products will need to be in place as a key framework condition. Putting a price on products rather than just materials was considered essential in order to ensure it encompasses all stages of the value chain. A simpler version of this (e.g. CO_2 pricing on fossil fuel extraction) could be an interim solution. It was agreed that the income from CO_2 pricing should be used exclusively to incentivise 'greener' production (e.g. subsidising renewable energy or investment in new technologies).

The group discussed different levels of governmental involvement (including public investment in breakthrough technologies/infrastructure and nationalisation/public ownership), but concluded that from an industry point of view, targeted public funding will continue to be the best option.

Finally, participants highlighted the need for enhanced transparency, communication and cooperation between policymakers, industry (across industries and value chains) and society as key drivers for industrial decarbonisation.

7. Outlook

This report marks the last Deliverable in Work Package 3, in which all work is now completed. Results summarised here will inform further work in other Work Packages, particularly Task 5.4 on the identification of synergies and trade-offs at different levels of governance. The results of Work Package 3 will also inform Work Package 6, particularly Task 6.1, aimed at better understanding the challenges of scaling up and mainstreaming low-carbon innovation.

This Task, as well as the work package as a whole, made it clear that over the past three or four years there has obviously been a shift in what drives low-carbon innovation. Many of the innovations analysed throughout Work Package 3 preceded the Paris Agreement and were mostly not particularly driven by goals of deep decarbonisation. The workshop in the context of work package 3 "Transition to fossil-free industries: technology pathways and policies" (March, 2019 in Brussels, cf. D 3.5) made it clear, among other things, that both political and industrial actors are strongly committed to contesting the future path towards a low-carbon economy and are already engaged to overcoming or eliminating certain structural obstacles.

In particular, if these two groups of actors are genuinely aiming to achieve the objectives of the Paris Agreement, the framework conditions for low-carbon innovation should improve. In particular, this could change current barriers towards

- (existing and future) regulation fostering a low-carbon transition and penalising high-carbon activities
- a lack of financial and organisational public support for low-carbon initiatives
- availability of 'green' energy for production processes (mainly electricity and hydrogen) due to governmental support for an increase in the share of energy from renewable sources
- public support and demand for sustainably produced goods, especially if it becomes a decision criterion in public procurement

Hence, by means of political commitment structural barriers for low-carbon innovations, including those already being developed by industry, could be removed and already existing drivers could be reinforced.

Society could also strongly influence the development of drivers and barriers for decarbonisation innovations. Recent developments and civil society movements (e.g. Fridays for Future) show that citizenship can put pressure on the need to implement decarbonisation measures. Not only in their role as voters, but also through their involvement in constructive and participatory processes that enable citizens to take active part in the development of social innovations and visions for the future of decarbonisation. As consumers, substantial changes in demand make the industry follow in terms of product supply and public image. In order to foster such changes, ways must be found to raise consumer awareness of climate-related issues relating to basic materials much more intensively.

Obviously, for companies to engage in low-carbon innovation processes, these have to involve the prospect of future economic gains. Against this backdrop, it is nevertheless interesting to note how many of the analysed innovations depend on personal motivation, regional effects, networks, etc., while reducing carbon dioxide emissions is only one of many drivers, and often drives innovation in an indirect way. For future decarbonisation, this shows the importance of having broader sustainability strategies and approaches to innovation and diffusion of solutions, ones that are bespoke to different sectors, cross-sectoral solutions, or value chains. These strategies should also include different types of instruments, e.g. regulatory, economical, informational/educational ones.

It also implies one important factor which has often been disregarded so far, the interaction between all different (groups of) stakeholders. This applies to policymakers, industry (across industries and value chains) and society. Increasing communication between those actors appears to be a promising driver for more transparency and cooperation for low-carbon innovations.

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