REINVENT – PROJECT NR 730053

# Implications for modelling decarbonisation

## Deliverable 6. 5

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# 1 Motivation and aims

The REINVENT consortium has utilized an co-production process between modellers, researchers and industry actors to develop new decarbonisation pathways for heavy industry. This method has been applied to two different kinds of modelling frameworks, allowing us to gain experience in applying it to a bottom-up industry model (WISEE-EDM) and an integrated assessment model (IMAGE). In this deliverable we reflect on the **implications, potentials and limitations for modelling decarbonisation pathways for industry**. To do so we synthesize the output of Deliverable D4.2 (modelling and literature review) (Van Sluisveld et al., 2018), Deliverable 4.4 (workshop on industry modelling) (van Sluisveld et al., 2019), Deliverable D4.3 (application WISEE) (Schneider et al., 2020) and Deliverable 4.10 (application IMAGE) (van Sluisveld et al., 2020).

In chapter 2 of this report we take stock of the insights acquired from literature and the REINVENT modelling. In Chapter 3 we reflect on the REINVENT process of modelling decarbonisation and conclude.

## 2 Landscape of modelling industry decarbonisation pathways

Throughout the duration of the REINVENT project a broad analytical spectrum of decarbonisation pathways has been included in the scope of assessment. Perspectives from a wide range of model frameworks have been analysed, encompassing optimisation, simulation and engineering models that have been used to underpin various long-term perspectives for industry. In this chapter we summarise the representations of industry and the considered decarbonisation strategies across the board of these modelling frameworks.

### 2.1 Modelling frameworks and scenarios

In reviewing the broader literature on industry decarbonisation (see Table 1) we find that industry is represented to various extents: in global integrated assessment modelling, regional systems modelling and specialised industry modelling:

- Global integrated assessment models (IAM) mainly include an aggregate representation of industry, for which some include a more detailed representation of key heavy industries. The representation of these individual sectors are not consistently represented across the global IAMs.
- The regional modelling tools are tools that analyse system impacts on a more spatial explicit level. As a result they include a more detailed representation of industries in e.g. a European or national context.
- Several reports also address industry decarbonisation in an industry-specific context. These studies maintain clear boundaries to a single industry and/or value chain.

The overview provided in Table 1 is not considered to be exhaustive, but rather an opportunity-driven pool of pre-existing decarbonization perspectives for industry to represent “the best available knowledge”.

**Table 1 - Overview of studies on industry decarbonization, the analytical framework underpinning the study and the level of industry detail it has included.**

| Models | Full sector | Iron & Steel | Aluminum | Cement | Non-metallic mineral | Non-energy use | Pulp & paper | Food | Other | Reference |
|---|---|---|---|---|---|---|---|---|---|---|
| **Integrated assessment models** | | | | | | | | | | |
| **AIM-CGE** | x | x | | / | x | x | x | x | x | (Edelenbosch et al., 2017) |
| **DNE-21+** | x | x | x | x | | x | x | | | (Edelenbosch et al., 2017) |
| **GCAM** | x | | | x | | / | | | x | (Edelenbosch et al., 2017) |
| **Imaclim-R** | x | | | | | | | | | (Edelenbosch et al., 2017) |
| **IMAGE** | x | x | | x | | x | x | x | x | (Edelenbosch et al., 2017) (Van Sluisveld et al., 2018) |
| **MESSAGE** | x | | | x | | x | | | | (Edelenbosch et al., 2017) |
| **POLES** | x | x | | | x | x | | | x | (Edelenbosch et al., 2017) (Förster et al., 2013) |
| **TIAM-UCL** | x | x | | | x | x | x | | | (Edelenbosch et al., 2017) |
| **IEA-WEM** | x | x | x | x | | x | x | | x | (OECD/IEA, 2009, 2017, 2018) |
| **EPPA** | x | | | | | | | | | (Förster et al., 2013) |
| **FARM EU** | x | | | | | | | | | (Förster et al., 2013) |
| **TIMES-VTT** | x | | | | | | | | | (Förster et al., 2013) |
| **PACE** | x | | | | | | | | | (Förster et al., 2013) |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Regional systems models** | | | | | | | | | | |
| **WISEE** | x | x | x | x | x | x | x | | x | (Van Sluisveld et al., 2018) |
| **FORECAST** | x | x | x | x | x | x | x | x | x | (Hartner et al., 2019) (EC, 2018) |
| **CTI2050** | x | x | | x | | x | | | x | (ClimateWorks Foundation/ECF, 2018) |
| **PRIMES** | x | x | x | x | x | x | x | x | x | (EC, 2018) |
| **TIMES PanEU** | x | | | | | | | | | (Förster et al., 2013) |
| **PET** | x | | | | | | | | | (Förster et al., 2013) |
| **GEM-E3** | x | | | | | | | | | (Förster et al., 2013) |
| **Industry models** | | | | | | | | | | |
| **CITT** | | | | | | x | | | | **(CEFIC/Ecofys, 2013)** |
| **Pathway model** | | x | | | | | x | x | | (WSP Parsons Brunckerhoff / DNV GL, 2015a, b, c) |

The analytical challenges being studied with the various modelling frameworks are also reflected by the pool of scenarios (see Figure 1). As global integrated assessment models are tasked to assess decarbonisation pathways in line with a climate objective, these scenarios are well represented from a higher aggregate level (leading to a holistic but not necessarily a detailed sectoral perspective). To a more limited extent various regional models also provide more aggregate perspectives on an sectoral level, which have contributed with more exploratory work on decarbonisation potentials by analysing specific technology routes ("Tech potential"). More limited numbers of scenarios exist on the level of individual industries – characterised mostly by regional systems models providing some perspective of decarbonising along a climate objective or through technology-oriented strategies.

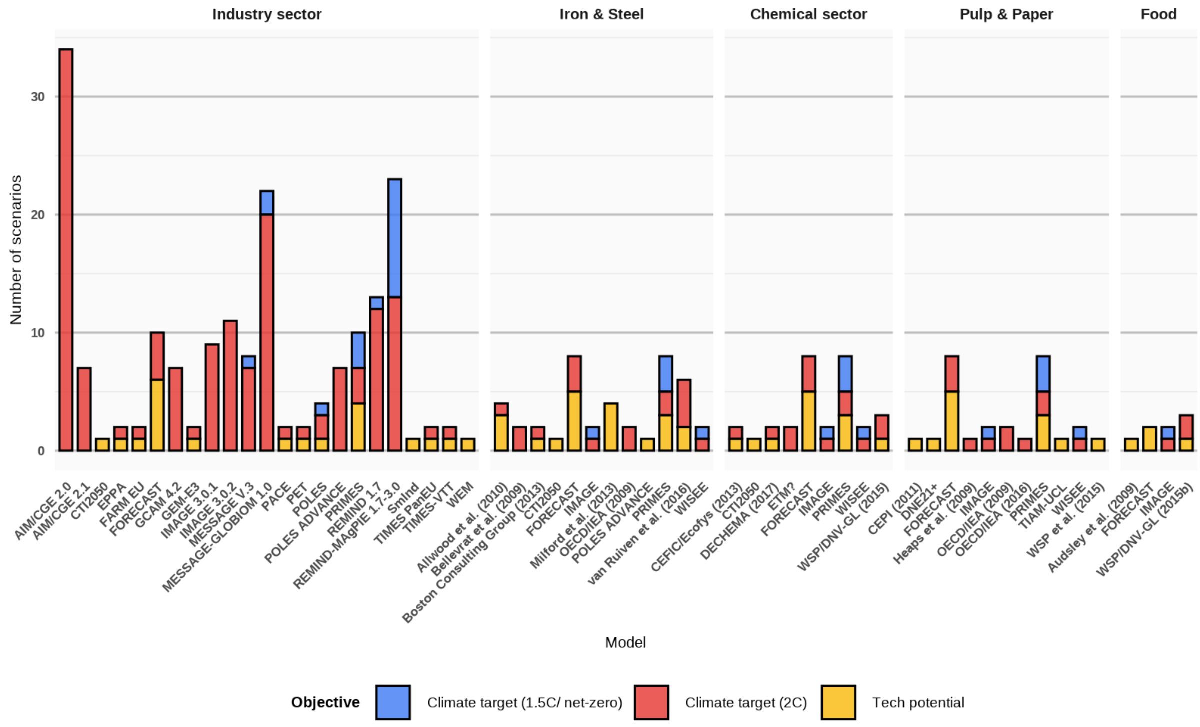


**Figure 1 - Overview of decarbonisation pathways being generated by the academic and non-academic community**

## 2.2 Decarbonisation strategy depictions

### 2.2.1 Modelling resolution

To get more in-depth knowledge about the response strategies represented in computational models, the REINVENT project hosted a stakeholder workshop (van Sluisveld et al., 2019) to systematically compare the three modelling frameworks as identified in section 2.1. The invited modellers were asked to indicate how explicitly they incorporated key mitigation strategies into their models. We identified and clustered the reported strategies to commonly shared elements:

1. **Energy innovations**: all decarbonisation strategies that refer to innovations related to the more efficient use of fuels, or using fuels with a lower carbon content than hydrocarbons, for driving the production processes (e.g. fuel switching, energy and thermal efficiency improvements);
2. **Process innovations**: all decarbonisation strategies that refer to innovations related to the efficiency or carbon removal capacity or feedstock uses in the production process (e.g. CC(U)S, technology innovations, feedstock substitution);
3. **Material innovations**: all decarbonisation strategies that refer to innovations related to the use of materials (e.g. consumption, material efficiency, end-of-life measures).
4. **Cross-sectoral interaction**: all activities that lead to industry decarbonisation via the use of two or more industries collaborating together;
5. **Non-technical innovations:** All strategies that relate to new (financial) decision-making drivers or actor behaviour.

The workshop underscored the large variety of depicted solution strategies, spatial and technological representations, number of represented industry sectors, degree of system integration and the level of included detail. Overall, the selected computational models include a more cost-effective and technology-oriented solution structure, broadly covering a similar representation of mitigation strategies albeit at different degrees of representation. We find that IAMs are generally more energy focused, yet have a broader value chain coverage (albeit with a lack of explicit representation). Regional modelling tools also have an energy orientation, although actual production processes are represented in more detail. Industry models specifically show a detailed (explicit) representation of the industry, but tend to offer gate-to-gate perspectives only.

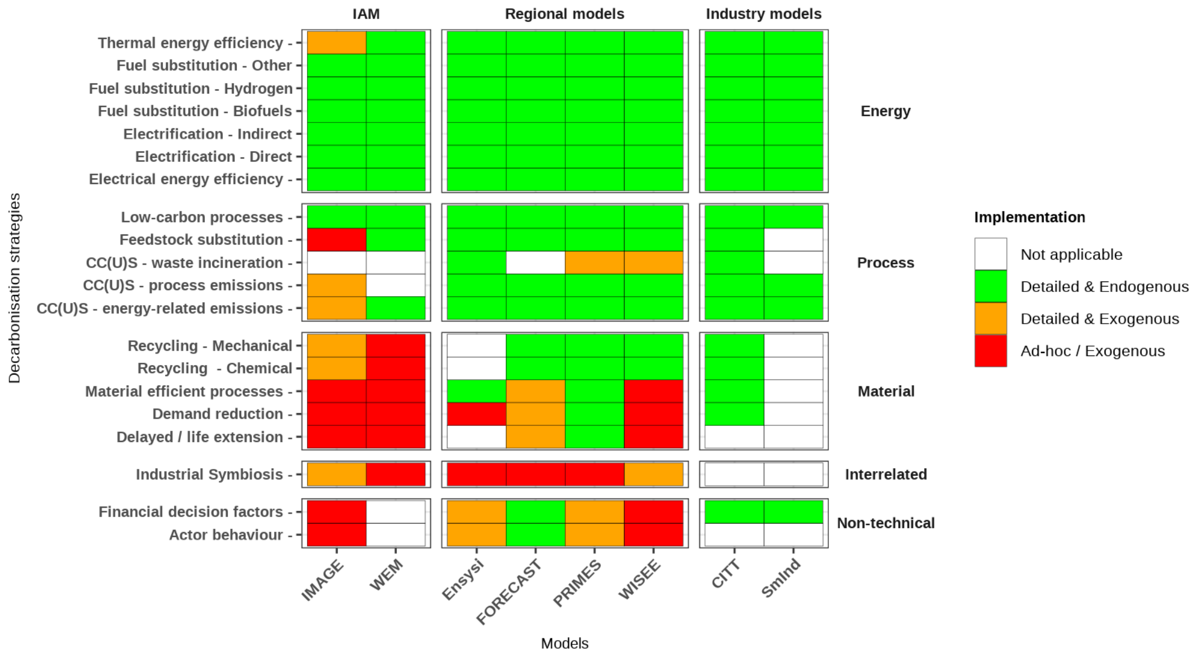


**Figure 2 - Overview of representation decarbonisation strategies per class of model**

The work in van Sluisveld et al. (2019) also considered whether the models where fit for purpose – leading to a survey distributed among industry experts to question them about the importance of various mitigation strategies in the mid to long term. This survey showed that the two most anticipated short-term mitigation strategies by industry (material and thermal efficiency) are those that find the least explicit representation in modelling instruments. The findings imply a structural deficit in models to represent short-term mitigation potential in industry.

For the long term, the industry perspective starts to substantially diverge, making it also very clear that (1) there is no consensus on the future direction of industry and (2) tailored strategies need to be designed for each industry separately (so aggregated depictions of industry are really not useful). Not much is envisaged for industry symbiosis by either industry experts or models, despite a high valuation of literature on this topic.

### 2.2.2 Industry resolution

The decarbonisation potential that is reflected in any quantitative computer model is a result of the degree to which decarbonisation strategies and the industrial value chain itself can be represented. From a top-down modelling perspective, energy-oriented strategies can be well represented as these follow a similar rational throughout the whole value chain. Given the heterogeneous character of many of the bulk material industries and their value chains, more tailoring is required to represent the specific decarbonisation strategies in each industry. As shown in Figure 3, using the IMAGE model as an example, this has resulted in different resolutions across the various industry representations. Endogenous decision making on the level of material and heat use and processing are found to be less frequent and detailed represented, leading to an overall focus on fuel switching and carbon capture and storage within the model framework.

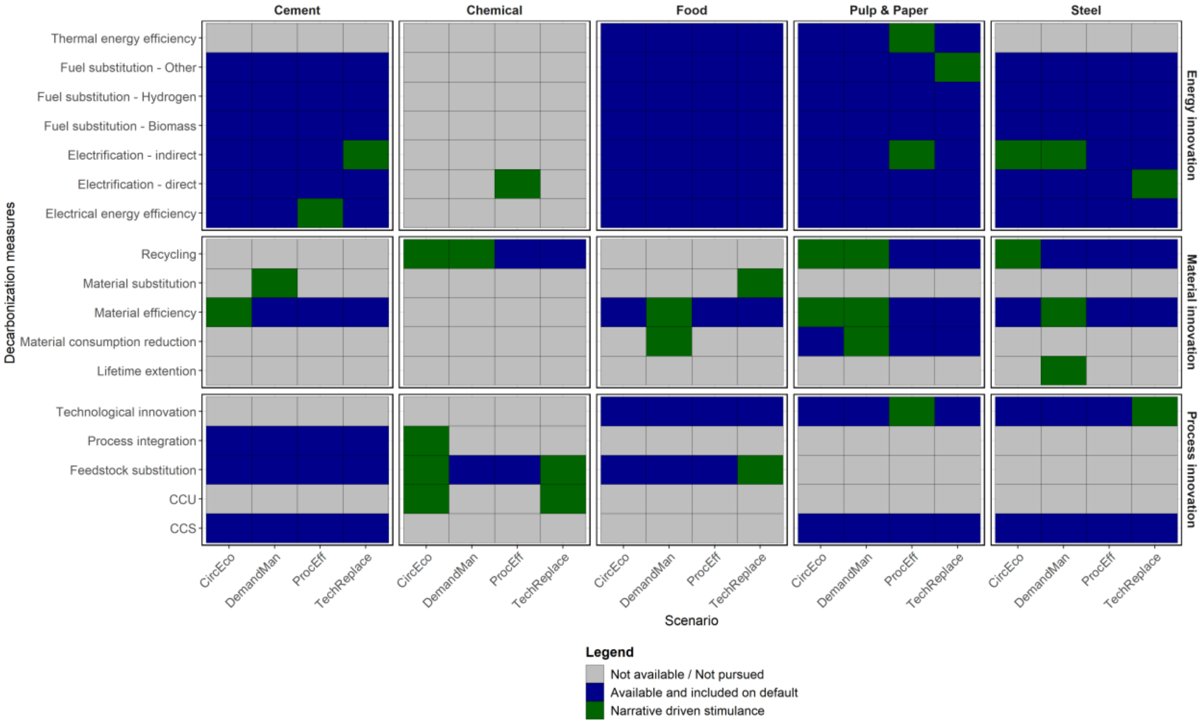


**Figure 3 - Overview of the decarbonisation strategy representation in the IMAGE integrated assessment model**

## 2.3 Mitigation potential

By decomposing the results of these different modelling frameworks into $CO_2$ emission reduction and final energy reduction (Figure 4), we see a wide diversity of potential decarbonisation pathways. Projection here both indicate either immediate decarbonisation availability to technically never.

Some general observations show that, although not robust given the absence of comparable data in some of the studies, global integrated assessment models tend to attribute a greater potential for energy efficiency measures than any other modelling framework. Only in one exception (IMAGE (2020) for the Iron & Steel sector) the total energy consumption increases, which is a result of the REINVENT process in which greater focus has been placed on specific technology options.

Regional systems models appear to offer a greater direct decarbonisation potential, as can be deducted from the greater availability of negative emissions in the chemical sector than projected by the global integrated assessment models. In a single instance, this is also underscored by an industry specific study (DECHEMA, 2017)(going to -200 compared to the index year).

Finally, scenarios that include a broader value chain perspective, e.g. through attributing greater emphasis on circularity, CCS and lifestyle change, tend to depict a greater decarbonisation potential or deeper negative emission pathway for industry than those that do not.

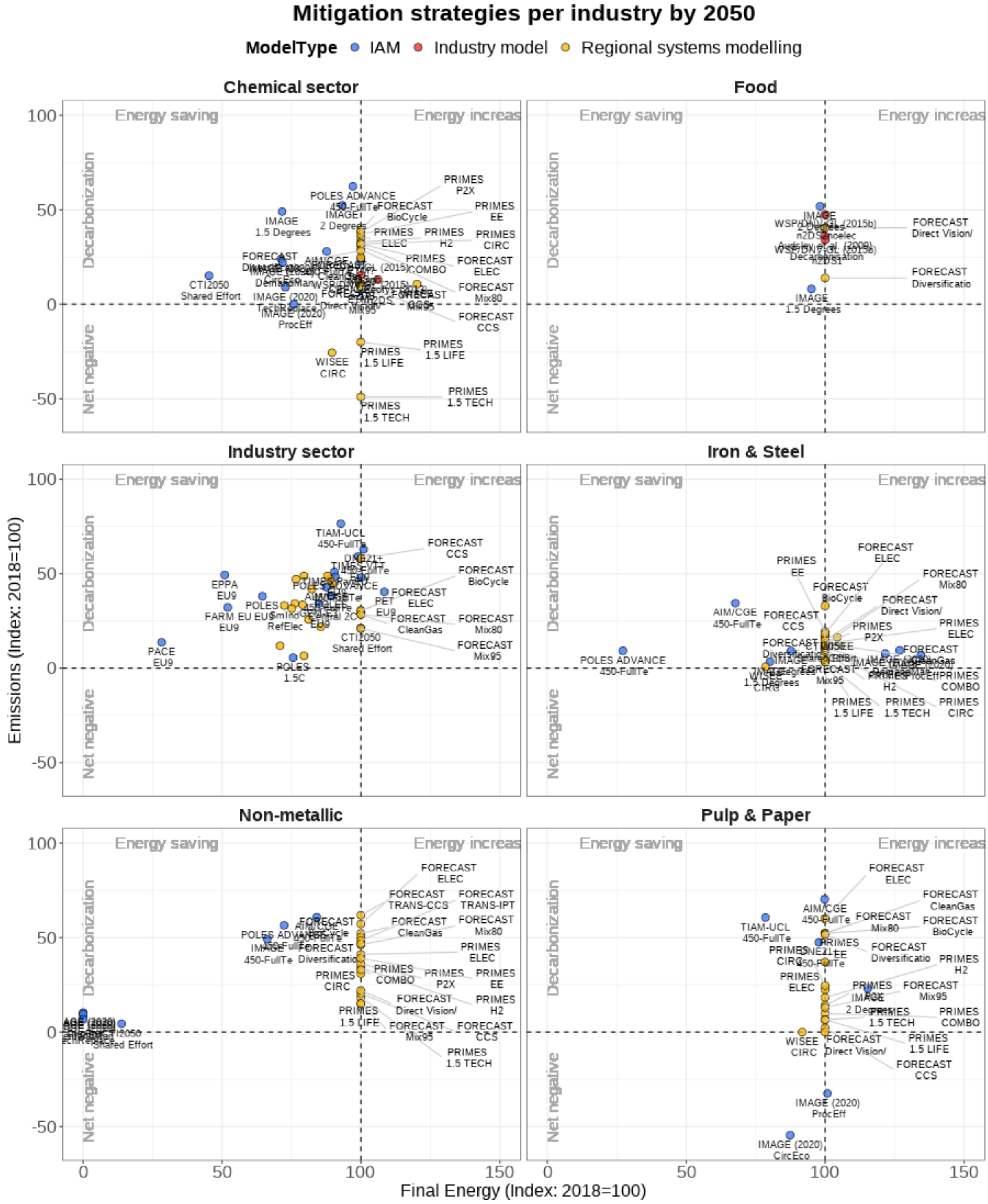


**Figure 4 - Overview of decarbonization strategies per manufacturing industry and class of model.**

Two data points by IMAGE (blue) go off-screen in the Pulp & Paper sector as a result of biogenic carbon capture and storage. One data point (DECHEMA, red) goes off-screen in the chemical sector. PRIMES and FORECAST studies as reported in EC (2018) and Hartner et al. (2019) did not include information on Final Energy use with a reference to a start year and have been fixed to 100.

# 3 Discussion and conclusions

The REINVENT project has developed decarbonisation pathways for industry via stakeholder dialogues, joint workshops and case-studies. These prospective systems have been assessed with two different modelling frameworks: a top-down integrated assessment model (IMAGE) and a bottom-up regional systems model (WISEE-EDM) (respectively presented in van Sluisveld et al. (2020) and Schneider et al. (2020)).

From an integrated assessment modelling perspective, the REINVENT project has allowed for a critical evaluation of how (1) industry and (2) the various decarbonisation strategies are represented in the model. Overall, more detail has been considered necessary in the IMAGE model to represent the specific decarbonisation narratives per industry. Given the limited amount of spatial and technological explicitness of production processes, difficulties have been experienced in representing broader value chain transformations for both homogeneous (such as the steel and cement sectors) and more heterogeneous industry sectors (such as the plastics and food sector). Several new modelling developments, instigated through the REINVENT project, have led to interesting new research avenues that could be further explored.

From a more bottom-up regional systems modelling perspective, the technical detail represented in WISEE-EDM allowed to better tailor the analyses to the stakeholder discussions and available materials on industrial decarbonisation. The REINVENT project has offered a framework of analysis (WP 3) to which the various imaginable strategies could be structured and combined to scenario storylines to provide consistent input parameter sets for the modeling exercises.

However, in both cases, many questions about (1) infrastructural needs and energy system integration and (2) socio-material or cultural aspects, in particular those relating to material consumption and substitution, have remained. Earlier work has provided some evidence that a broader value chain perspective may lead to higher decarbonisation potential. However, in order to take these kinds of narratives into consideration, the existing modelling frameworks need additional sources of information.

Both topics indicate that new collaborations and specified research efforts are needed to broaden the scope of scenarios on industrial decarbonisation. For integrated assessment modelling, this implies a clear challenge to represent the multitude of sectoral interactions and dependencies more explicitly and dynamically. To gain a comprehensive integrated perspective, reflecting both the opportunities and trade-offs within and between sectors and systems, this would require a better coverage of the challenges revolving around energy, heat and material services, demand, substitution and supply.

For regional systems modelling new collaborations and research efforts could focus on more participative modelling approaches as described in e.g. Espert et al. (2016); Lechtenböhmer et al. (2015). Involvement of industry and also societal actors in the discussions of scenario storylines, as done in REINVENT, is definitely an important aspect of mutual learning between industry and science with potentials for true co-creation of visions, e.g. for a climate neutral European industry. New research efforts could also focus on increasing the resolution in the model, which would allow exploring the dimension of spatial distribution and locational factors linked to decarbonisation.

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