Reflecting on the dynamics of decarbonisation

Deliverable 1.4

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1. Introduction

In the first year of the project, REINVENT produced an analytical framework (D1.3) in order to both open up the lines of enquiry that the project should pursue and provide a meeting point for the diverse research undertaken across disciplines and work packages in the project. In this report, we revisit and reflect on this analytical framework and consider the insights that our work has collectively generated with respect to two key aspects: first, how we understand the dynamics of *inertia and innovation* that shape the possibilities and pathways of transition; and second, how we assess the *capacities needed* to enable further innovation for decarbonisation.

When it comes to understanding transitions as a product of the dynamics of ***inertia and innovation***, based on an extensive review of the literature (D1.1), the starting point of our analytical framework was that to date the potential for decarbonisation in the energy- and carbon-intensive sectors of the economy has predominantly focused on the *production* stage of the value chain which in turn has limited the ways in which transitions have been conceptualised, researched and analysed. Taking a whole-system, value chain approach to the investigation of the opportunities for (and challenges of) decarbonisation in these sectors necessitated opening up existing conceptual approaches particularly with regard to four key dimensions.

- *The agents of change*: rather than focus on the narrow range of actors included in much of the literature to date, we proposed to open up the question of which are the most important agents of change in transitions in order to understand their individual and collective effects on shaping possible pathways for decarbonisation.

- *Developing the conceptualisation of power:* our review found that questions of power often remain implicit and also focus on the dynamics of political-economy or relations between the state and capital that are seen as having the preiment role in shaping the conditions of possibility for transitions. While supporting the importance of this perspective we have sought to open up the question of the *cultural* dynamics of transitions and to expand our conceptualisation of power and its operation accordingly.

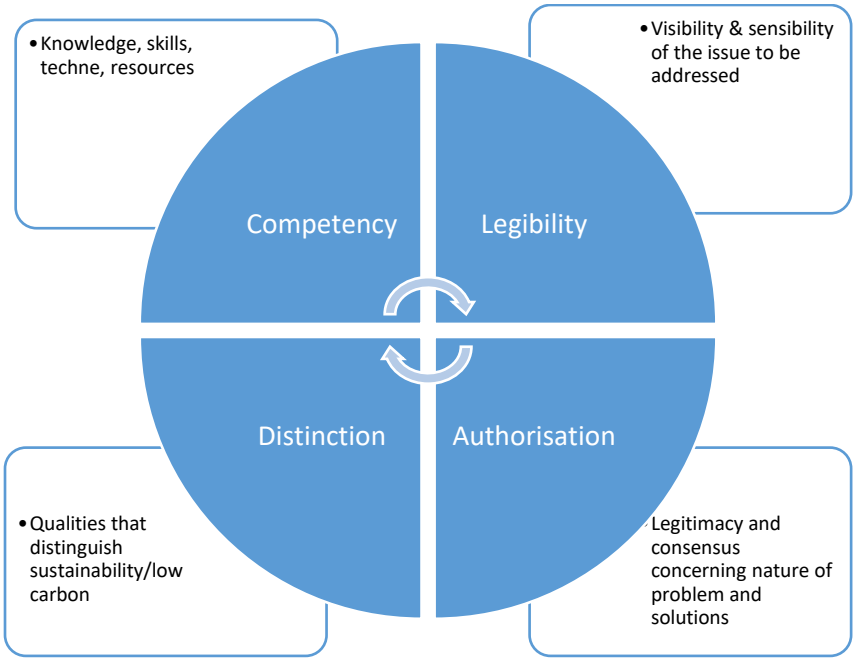
- *Understanding how materialities matter:* despite the concern with the material sectors of the economy, questions of materiality are often neglected in accounts of low carbon transitions. We sought to insert the importance of recognising the materiality of transitions in our analytical framework – for example by attending to how the material qualities of resources shapes what it is that they can become, or attending to how claims for the material qualities of products shapes their demand.

- *Geographies of deep decarbonisation:* taking a whole-system, value chain approach has necessitated engaging with the geographies of global economic production, resource flows,

investment, consumption and waste in these sectors in order to analyse their potential for decarbonisation.

In addition to providing the basis for understanding the nature and dynamics of transitions for deep decarbonisation, our analytical framework also sought to provide the basis for understanding ***how specific interventions*** can leverage change. Drawing extensively on existing concepts of innovation and governance, the framework put forward a set of ***intervention capacities*** that our review of the literature suggested would shape the extent to which specific interventions (or what are sometimes termed niche innovations or governance experiments) might be capable of generating change (Figure 1). Our analysis has specifically examined what the interventions analysed in REINVENT tell us about the possibilities for *scaling innovation* (D6.1) and for *building momentum for change* (D6.2). Here we revisit those capacities that we hypothesised in the analytical framework (D1.3) would be critical for leveraging change on the ground in the light of the case-studies we have undertaken and consider the consequences for how further capacity for transitions can be generated in the future.

Figure 1: Capacities Required to Realise the Potential of Interventions for Low Carbon Transition



In order to reflect on the value of the analytical framework when it came to these two central ambitions – understanding the dynamics of inertia and innovation and providing the means through which to analyse the capacities required to realise the potential of interventions for low carbon transitions – the project team were asked to consider the insights the analytical framework had generated for their work. These insights were collected using a short template sent to members of the project team and then collated and systematically organised in order to be able to compare and contrast our reflections across the different areas of the projects' work. In the remainder of this report, we present these findings. Section 2 focuses on how the analytical framework has been used to generate insights concerning the dynamics of inertia and innovation, while Section 3 considers what we have learnt about the capacities of interventions required to generate low carbon transitions. Section 4 provides a short conclusion.

2. Between Inertia and Innovation: Understanding the Socio-Material Dynamics of Transitions

Our analytical framework proposed four entry points through which investigation and analysis could enhance our understanding of the nature of decarbonisation pathways – agents of change, power, materialities and geographies. In this Section we gather insights from across the project team to reflect on how far these entry points have generated new insights about the potential for deep decarbonisation as well as their limitations.

2.1 New Agents of Change

Taking a 'whole economy' and value chain approach has revealed that the sectors under scrutiny in REINVENT – meat and dairy, pulp and paper, plastics, and steel – have complex value chains involving multiple actors. This is a particular challenge when it comes to ***finance***, as we discussed in our report published jointly with the UK's RGS-IBG, for: "solutions require a complex set of [financial] actors to work together" across and between value chains (Bulkeley and van Veelen, 2020, p.3). Overall, our research suggests that there are relatively few new financial agents of change entering into the field of deep decarbonisation in these sectors of the economy. We find, for example, that even in banks that have a strong focus on issues of responsible investment, there is no explicit interest in developing investment products to support innovation or transition in these sectors. Likewise, there are few examples of the use of new financial instruments – even the popular green bond – supporting innovation for decarbonisation. We do however see increasing interest from third-sector organisations in the development of standards, certification, and instruments to increase the transparency of investment in these sectors – particularly in relation to food – which may in turn spark increased levels of disclosure and shifts in the landscape of investment over the next decade, given that such initiatives have also triggered such shifts in relation to climate change more generally. There is also evidence of venture-capital being drawn into the 'meat alternatives' pathway. Here financing and research & development for 'cultivated' meat is being undertaken by new entrants seeking to disrupt the existing livestock/meat sector, but also by incumbent meat and food companies seeking to protect market share through partial buy-in into new technologies and products.

The value-chain approach has also served to help identifying new patterns of agents of change. In the REINVENT case studies we have seen plenty of examples of how agency is distributed throughout, as well as across, the value chains we have studied. Although large incumbent actors are still important for the development of these industries, it is clear that specialised engineering firms and other technology developers, as well as actors further downstream, can initiate change and have a large impact by forming strategic alliances. That being said, several case studies have also shown the importance of using specific windows of opportunity to push for and support a decarbonisation agenda.

For instance, the case of DuraSense illustrate how the company took advantage of a restructuration of an old paper mill to develop the biocomposites business. Despite the diversity of agents in terms of size, age, and market position our findings suggest that reaching out of the comfort zone into new types of solutions, markets, and business models is very difficult for most industrial actors. They thus tend to strongly promote incremental solutions rather than taking a value-chain or end-user perspective on decarbonisation. For instance, steel and cement manufacturers will aim for low carbon reinforced concrete and rebars while construction companies may look for wood or alternative materials.

While certain types of agents are commonly assumed to drive change, others are assumed to resist it – for instance, start-ups and civil society organisations are often assumed to drive change, while large established firms are assumed to resist it –, our work on the pulp and paper industry suggests a more elaborated understanding of the roles of agents of change. First, there is considerable variation over time in the types of actors involved in change agency and the same type of actors may take very different positions in different phases of a transition. Moreover, change agency may take very different forms; some agents may drive the development of radical new products and processes, while others may exercise change agency through institutional entrepreneurship, or by coordinating development efforts across a wide range of actors. This thus highlights the considerable heterogeneity in change agents, both in terms of 'who they are' but also in 'what they do'.

Our work on momentum and scaling, echoes above findings on expected and new agents of change as well as their shifting roles. First, we see how incremental actors are still critical in setting the scene in which actors seek to scale and build momentum for their innovations. For instance, the steel sector is characterised by high barriers of entrance, why it is probable that introducing HYBRIT was possible since it was done by incumbent actors. Similarly, the clothing sector is dominated by large, powerful actors who dictate demand, and thus also supply, of the materials used. This can help explain why the small company Tierra struggled to find the required bio-based materials for their fossil-free outdoor jacket *Deterra*, and also why it appears more as a concept demonstration rather than a scalable innovation. Our work on momentum and scaling has however sought not only to identify new of agents of change, but also to understand new ways to be involved in change-making. By introducing literature from Material Politics and Cultural Politics we were able to identify roles of agents of change that stretches beyond introducing or supporting new innovations, and instead focus on politicisation and production of meaning. For instance, we see how individuals are not solely involved in making change as end-consumers but also through lifestyle choices and activism. In the case of Oatly, we see how the idea of a 'post-milk generation' was cultivated by adamant supporters of the oat-milk company, which has been critical for the spread and acceptance of the innovation. Interestingly, parts of this community turned against Oatly when they brought on investment firm Blackstone, which suggest that new agents of change might mean a less inert system. We also see how members of the zero-waste movement have been critical in the politicisation of plastic, and bringing it to the fore amongst environmental concerns. Thus, despite a limited scaling of their innovation, zero-waste supermarkets are catalysing a conversation in the European retail sector around packaging and sustainability. We suggest that these new lenses on are critical to acknowledge how new agents of change could instigate wider processes of contestation and transformation at the sectoral level and thus broaden the understanding of what it means to be an agent of change.

2.2 Power

Placed at centre in the analysis, REINVENT has sought to examine how power shape inertia-innovation dynamics in a variety of ways. As a first way of doing so, we have attended to how investments, or lack thereof, shape possible action in the regime. In part, the limited nature of financial investment in the REINVENT sectors is testament to their incumbency and the ways in which capital is accrued through existing companies and reinvested internally, such that much of the investment being made in future high-carbon investments is derived internally (particularly in relation to steel, paper and plastics). This in turn suggests that the power to change investment in these sectors will, as is the case for coal, oil and gas, be most likely to arise from shareholder pressure and in particular from the actions of large institutional investors who hold significant shares in high-carbon sectors of the economy (e.g. pension funds). While such institutional investors have been increasingly mobilised around the fossil-fuel economy, we have yet to see the same level of mobilisation when it comes to carbon-intensive sectors such as those addressed in REINVENT. At the same time, we see evidence that these sectors are also highly dependent on state finance and, particularly when it comes to steel and meat/milk, are interwoven into the visions of the past and future of national economies. These relations are in turn supported by significant subsidies for existing modes of production, including by the EU itself, but also open up the possibilities for new forms of state-based financing for innovation in these sectors – given how much European nation-states and the Commission have at stake. This is evident in relation to high capital costs for investing in new energy technologies for steel (e.g. HYBRIT) and the continued financial support being given to trials of CCS (which may be particularly of relevance for the steel sector).

Moreover, we have sought to map governance structures to understand how such come to shape decarbonisation change. The energy and emissions intensive industries are not regulated strongly through international institutions and conventions, which makes it difficult to insert climate governance in existing governance structures. In the EU the traditionally important heavy industries with large, old incumbent firms have remained powerful. Individual firms and trade associations have efficiently created barriers for change and decarbonisation – for instance, by lobbying for the creation of large gaps in the EU ETS providing – and arguing that decarbonisation in these industries would be extremely difficult. However, it seems like these positions are shifting and that the alliance built around this issue is breaking up, since some industries (e.g. the steel industry) are now promoting and supporting decarbonisation as a possibility. Meat and dairy, which is closely connected to the agricultural domain and CAP, is seemingly operating under different circumstances. On the other hand, meat and dairy is much more sensitive to the power of consumer pressure which the other industries are rather distant from.

In addition to this, our work on scaling and momentum has sought to broaden the understanding of how power shapes inertia-relationships. While socio-technical regimes are commonly understood as fairly stable, transforming through reaching a ‘new stable’, we have examined regimes’ contingent character by attending to how these are re-produced and held together in certain assemblages. A notable example of this is Oatly, which is thriving from, rather than held down by, the resistance they meet from incumbents. Zero-waste supermarkets are, on the other hand, struggles to ‘break through’ the regime as an innovation. Despite this, they are highly involved with shaping regime dynamics

through politicisation of plastics and agenda-setting. Moreover, zero-waste supermarkets prefigure food systems by demonstrating new ways of doing things. Here, rather than seeming 'fixed', inertia-innovation relationships appear as dynamic, reaching temporary assemblages that are always up to contestation. Although the power of new agents of change may be limited in material/infrastructural terms, most notably in the case of zero-waste stores, they are often very effective in cultural and political terms. Thus, power is here conceived not as existing on a singular continuum, but as a relational process that is revealed through the particular actions which agents take within regimes.

2.3 Materialities

As our findings suggest, materialities are critical in shaping inertia, which in turn shape innovations' possibility to spread and become normalised. When studying these industries, it is critical to acknowledge the very short lifespan of carbon in our economies. Commonly, even in plastics, carbon travels from resource to waste in just a few weeks or months, and in the other industries the carbon is turned into emissions immediately. At the same time, it is critical to take time-horizon problems into account; carbon-intensive infrastructure currently made or planned operating with 30+ year time horizons, which, in the example of plastics, leads to consolidation in the petrochemical industry between upstream/downstream. Moreover, investments in packaging machinery – in most companies these investments are larger than in food production itself – further re-produce current business models and is extensive use of (and dependency on) fossil plastic. As such, materialities are involved in shaping massive lock-in problems in most sectors studied.

The impact of such long-term investments has also been acknowledged in our work on building decarbonisation scenarios for industries. Although as with most modelling endeavours to date the 'economic life' of investments is regarded as rather fixed – for example, the potential for political and economic decisions to retire 'usable' infrastructure such as coal plants ahead of their expected lifespan is not considered. At the same time, modelling is beginning to account for how the materialities of these sectors are not set but change over time. The dynamic in the WISEE module (one of the two models used) integrate stock reinvestment as one key factor; both in steel and plastics the model takes into account how lifetime expiry of stocks may open up windows for technological change. Within plastics the lifetime of steam crackers and refinery production stock (40–50 years), within steel blast furnaces need a major retrofit after 20–25 years of operation time, and within pulp and paper's there are 15 years investment-cycles. According to WISEE's two scenarios (CCS and CIRC), emissions within steel is projected to decline significantly not until 2030 when stock exchange begins and the phase-in of low carbon breakthrough technologies is possible. Similarly, investments in steam crackers made before 1975 will open up possibilities of technological replacement within plastics after 2025. After this, one of the CIRC scenario projects that waste- and bio-based production will be phased-in, although some steam crackers will still be needed. However, other parts of our work show an increasing demand for secondary steel. This is projected to lower demand for crude steel, which helps to lower emissions in a more gradual fashion than presented in the CSS and CIRC scenarios. Moreover, as projected in the work of narrative scenarios, consumption-based innovations (here referring to innovations seeking to achieve circular economy or reduce demand) are projected to unlock more early-on decarbonisation potential. This is particularly effective in the food sector – where dietary

shifts and reforestation decarbonise at the source –, but also apply for pulp and paper, plastics, and steel. We thus identify varying tendencies of how materialities shape inertia.

Due to institutionalisation of these sectors, they are taken for granted. Therefore, their role in our economies escapes scrutinization in several ways. Although their material properties are the outcomes of many years of technological development and evolution of social practices over generations, they are seen as self-evident and absolutely fundamental for our ways of life. This makes decarbonisation, which requires some changes in how materials are used, problematic and difficult. Not solely because alternatives may not always substitute one-to-one, but also because substitution in itself is beyond the thinkable. As thus, 'new' materialities may serve to prefigurate and politicise existing infrastructural systems. Being the 'skin of commerce', plastics is a material necessity for extensive supply change and large transports. Since zero-waste supermarkets promote removing plastic packaging entirely, they challenge the foundations on which current business models rely, which explains why they are so strongly contested by incumbents. Nevertheless, the innovation has made fossil plastics visible, and thus substitution, although not necessarily in a way that zero-waste stores would have it, thinkable.

We have seen many examples of how materialities shape innovations' ability to be become accepted as low carbon alternatives. As shown in the case of the bio-based jacket Deterra, the 'feel' and the function of some fossil textiles are hard to replace. Most notably, the stretchiness in Lycra is hard to achieve with bio-based fabric, which compromise function, but also a certain 'feel'. This reveals how the functional properties of, but also emotional attachment to, certain fossil materials shape reluctancy to move towards (re)new(able) ones. In a similar fashion, efforts to develop cultivated meat have been frustrated by the challenges of engineering lab-grown meat that has sufficiently similar materialities – especially mouthfeel – as meat. Products based on plant-based proteins supplemented with ingredients such as 'heme' (soy leghemoglobin) in the Impossible Burger have so far achieved a closer approximation of the taste and mouthfeel of meat than cultivated meat, despite the cellular materiality of plant-based products being less similar to meat. In the case of Oatly, harmonising materialities oat-based products were critical for its wide acceptance. Mimicking dairy in colour, packaging, and function paved the way for Oatly to be seen as viable dairy substitute. Moreover, creating an oat milk which requires refrigeration, we suggest, was key in order to align their product with Swedish cultural norms of buying fresh dairy milk. This suggest that examining intersections of desire, function, and materialities has been critical in understanding cultural aspects of inertia-innovation relationships. Moreover, they represent a more productive and less obdurate approach to the making of regimes, taking into account how linkages are generated through forms of cultural resonance and emotional attachment.

Perhaps one thing to reflect on here is the clear difference in the amount of attention being given to carbon investments in the fossil fuel sector in contrast to these high carbon sectors – it is clear that the lack of clear visibility of carbon in these areas means that they are currently under the radar when it comes to the active policies of institutional investors and the actions of the divestment movement. Another issue relates to the long investment cycles in many of these sectors, meaning that there are discrete windows of opportunity when the (lack of) availability of finance would make a significant difference to the future shape/emissions of the sector, e.g. the need for large amounts of capital for investment in replacement technologies or new solutions will be episodic rather than linear and is

currently poorly understood. Coupled with the long periods of return on investment, this may mean that we are missing opportunities to 'unlock' these sectors from future carbon emissions and 'locking in' high carbon dependencies over time.

2.4 Geographies

While previously understudied in transitions, our work in Reinvent takes geographies and spatiality of transformations seriously. One intriguing aspect of the geographies of low carbon finance relate to the roles of different stock markets and the kinds of companies that are listed. London, for example, is the key stock-exchange for a significant proportion of global oil and gas companies, and hence provides a particularly critical leverage point for deep decarbonisation (e.g. in terms of what might be required by companies listed on that exchange in terms of disclosure). Given the connection between oil companies and the plastic sector, this might also prove to be an important leverage for action in this sector. On the other hand, many other companies are either state-owned (at least in part) or highly dispersed (e.g. food retail companies are relatively distributed globally rather than being concentrated in specific stock-exchanges), reducing the leverage potential.

The geographical differences in the connection between key sectors and national governments is also of significance when it comes to considering the potential for the finance sector to become a key agent of change in diverse contexts. Where finance is readily available to incumbent industries, even increasing the volume of finance for alternatives is unlikely to provide a critical turning point. Instead, it becomes critical to consider how the financial system as a whole is becoming 'green' – how central banks and government investments, subsidies and incentives are (or are not) aligned with their ambition of becoming net zero. To date, there is evidence that this agenda is being advanced by the Bank of England when it comes to fossil fuel investments, but has not spilled over into other sectors as yet. There is also evidence that the Dutch National Bank is beginning to consider how far its own investments are both at risk due to the collapse of natural systems and how in turn they are contributing to this collapse, which has particular implications for both food/agriculture economies and mineral extraction, but this work is at an early stage of development. (DNB and PBL, 2020)

Since the geographies of renewable resources are fairly different to fossil ones, important questions have been raised both about who has access to resources in a decarbonised world. Of equal importance is attending to changing logistics, flows, and trade with these resources, since patterns could potentially be significantly different compared to those structured along flows of fossil resources. For instance, Tierra's creation of a fossil-free jacket both relied on and was constrained by the complex geographies of production in the textiles and clothing industry. While these geographies enabled Tierra to assemble a production network capable of producing the fossil-free jacket, the current global textile industry contains particular bottlenecks and favours large actors which required Tierra to compromise on specific aspects of the jacket's design and constrained their ability to quickly alter designs and scale up the volume of production. New geographies of renewable resources could also transform the relationships between regions by creating new centres and peripheries. Specifically, the decarbonisation of these sectors raises questions around how important clusters and regions such as, for instance, the ARRR (Antwerp-Rotterdam-Rhine-Ruhr), can develop in a post-fossil world. We

must thus look for alternatives for regional development in those regions that are highly entrenched in the high-carbon industries and we must also seek to understand to what degree knowledge bases and infrastructures in these regions are valid in a decarbonised economy.

Interestingly, our work on decarbonisation scenarios identify a potential in petrochemical sites such as Antwerp, Western Germany, Northern Spain and the Rhone delta. In a European perspective, these regions are projected to have the deepest cuts in steam cracking capabilities, why they have the potential to become adopters to power-to-plastics technologies. However, both Belgium and the Netherlands are countries with currently relatively low renewable electricity capacity, which will be a challenge for decarbonisation of the petrochemical cluster. Modelling of the adoption and diffusion of these technologies on a cluster level or has however not been the focus in our work, and neither has modelling renewable energy supply; further work is thus needed in understanding these dynamics. However, it is safe to say that just as proximity is critical in current clusters, so will it be in making of renewable ones.

Our findings also suggest that there are very different senses of scale in many sectors; there are disruptive upstarts locating sustainability on the local scale (very prevalent in zero-waste), incumbents operate with global scale. The separation between local and global scales can however be successfully challenged or bridged; making the local have global significance, or using global connections to operate locally. For instance, zero-waste supermarkets draw on global network of online zero-waste influencers, bloggers, and social media followers. However, our work has also sought to broaden the understanding of scale in socio-technical transformations by drawing on 'the scale debate' prevalent in human geography (see Bouzarovski and Haarstad, 2018) and its conceptualisations of 'the politics of scale' (Swyngdouw, 1997; Gonzales, 2006). By employing various understandings of (re)scaling in our work, the spatial processes of socio-technical transformations are analysed to a larger degree than preciously found in the literature. As such, we suggest, ongoing change and contestation that otherwise goes unnoticed can more easily be identified. For instance, while zero-waste supermarkets have not scaled up as in sized-up or reached 'higher' governmental levels, they have scaled geographically to other sites. Moreover, they are evidently involved with challenging current regime practices which incumbents are forced to respond to. While a single understanding of scaling would see how zero-waste stores have 'failed' to break through the inertia of the regime, others identify ongoing regime contestations. As such, the broadening of conceptualisation of (re)scaling serve to broaden the understanding of inertia dynamics.

2.5 Reflections

REINVENT's 'whole economy' approach is running as a red thread through our mapping of inertia-innovations dynamics. Through this approach, we are able to identify different positions of agents of change depending on their position in the value chain, but also able to identify widely different visibility of carbon-intensity in different parts of the value chain. The latter has been particularly notable in the different politicisation of plastics throughout the value chain. Plastics within food retail (packaging) has been highly politicised, although commonly problematised through its relations to marine litter rather than its carbon-intensity. If we instead examine plastics in textile in the clothing industry, we found that it has remained highly invisible. Plastics is thus an illuminating example of

how the dynamics of inertia and innovations must be analysed throughout the value chain and thus through their particular relations of both consumption and production. There are emergent discussions around both 'clothing recycling' and the embodied energy of new textile materials made of wood (e.g. Lyocell).

Another key part of our work on the socio-material dynamics of transitions has been the broad conceptual understanding of the four dimensions set in the framework. Our work echoes previous work of transitions in that power is centred around incumbent, large firms which direct decarbonisation and that this makes the actional space narrow for new innovations and actors. We have also found that existing government structures and regulations and long-term investments are key for setting the course of decarbonisation (or lack thereof), although positions are starting to shift and new alliances are made. Challenges remains to regional clusters of (fossil) production since geographies for renewable energy is rather different than fossil ones. There are however indications of the potential for a few such clusters to become early adapters of renewable technology, since short remaining lifetime of infrastructure opens up possibilities for substitution. We have also analysed the four dimensions with the lens of theories focusing on the emergent character of regimes. This has revealed ongoing contestations of meanings and how actors' politicisation represents new ways of engaging in change-making. Although innovations are not able to successfully establish themselves, they can instigate wider conversations within regimes. Similarly, new materialities have the ability to prefigure systems, although not disrupting such. We have also observed very different perceptions of scale of decarbonisation efforts; there are disruptive upstarts locating sustainability on the local scale, while incumbents operate with global scale. These 'gaps' can however be , and have to some degree already been, bridged as global networks are established.

As such, we have been able to take both the persistence and contingent character of regimes into account. Some activities – such as long-term investments in material infrastructure – shape enduring structures in regimes, while other more dynamic processes – such as politicisation or demand management – contest and challenge these seemingly fixed structures.

3. Analysing Intervention Capacities

At the heart of accounts of the possibility for transitions to low carbon futures lie specific interventions – niches, innovations or experiments through which new technologies, social arrangements or policies are tried, tested and accelerated. Our analytical framework sought to identify key 'ingredients' that were identified across diverse literatures as being important in terms of generating the capacity needed for such interventions to realise their potential in catalysing low carbon transitions. We found that this entailed:

*First, issues of **competency**, which include forms of knowledge, skills and resources to undertake the work of transitions. Second, **legibility** – the capacity to create a shared vision and sense of the potential for innovation and how its effects can be calculated and made commensurate with other values, goals and drivers. The third, **authorisation**, relates to the ways in which the capacity to govern is afforded through generating legitimacy and consensus in relation to the nature of the problem to be addressed and the viability of the solutions that are proposed. Finally, the capacity of being able to generate **distinction** relates to the work involved in being able to distinguish low carbon entities/processes/practices from incumbent high carbon alternatives in ways that allows their value to be recognised, communicated and mobilised.*

In this section, we revisit these categories and reflect on how far they mattered in the interventions that were in focus in our research and in turn reflect on whether these provide a useful means of explaining how and why some interventions are able to yield progress towards transitions whilst others are not.

3.1 Competency

Findings in our work show how specific innovations possess key qualities needed to render industries fully decarbonised. It also becomes clear that different types of innovations possess competences to pave the way for decarbonisation in different ways. Technologically-driven pathways – here referring to technological replacement (e.g. introducing processes that remove the need for coking coal as a reductant) and process efficiency (e.g. energy improvements, implementing the most efficient available technology) – have the potential to shape decarbonisation efforts long-term, since shifting investments 'locks' industries into a new decarbonised production process for a certain amount of time. According to our scenario narratives, full decarbonisation of industry is only possible with technologically-driven pathways. However, due to remaining lifetimes of investment in material processes, investments are projected to not be possible not until 2025–2030, and critical decline of GHG will thus happen after this in these scenarios. Consumption-based innovations – here referring to innovations seeking to achieve circular economy or reducing demand – possess different decarbonisation capacities. These projected to initiate emissions reductions sooner and thus show to unlock early-on decarbonisation potential, particularly within meat and dairy. Down-stream representation is limited and generally static in nature in the IMAGE model. The effects of material demand are thus mainly acknowledged through its reducing effect on primary material use, while the decarbonisation potential of material demand can be larger than so. Nevertheless, our work in this

matter has made some advancements on the examination of consumption-based innovations. Taking consumption-oriented demand reduction into account is by no means new, however our work has been able to account for secondary markets and material stocks, and the potential thereof, in a way that is notable. Further research is needed, especially in making the potential of down-stream dynamics and its potential more visible, our work in this matter nevertheless represents a key contribution to the research of these kind of innovations. Although it is hard to conclude with certainty, REINVENT's focus on examining the whole value chain could potentially have directed these broader understandings of decarbonisation dynamics.

Firm competencies are important for understanding when large, established firms become progressive forces for transitions. The propensity of such incumbents to pursue radical change is higher if they can utilise existing knowledge about markets or production processes. Cases from the pulp and paper industry highlight that incumbents are much more likely to venture into the development of new biobased products that may contribute to decarbonising other industries, such as plastics, if they can profit from existing competencies and leverage the competencies of collaborators from other industries, exemplified by the Äänekoski biorefinery development. Our work on the pulp and paper industry has however highlighted that suitable competencies is a necessary but not sufficient condition. Equally important is the motivation of firms to engage in such developments, which in turn depends on factors such as pressure from consumers and regulators, the possibilities of extracting higher value from by-products, and developments in markets from existing products. In summary, while relevant competencies are crucial, so is the motivation for utilising these competencies for radical innovation.

However, our examination of the case study identifies a general lack of competency in various areas. Firms in the studied industries have established knowledge bases and a very good understanding of their markets for both feedstocks and products. However, since decarbonisation efforts challenge the traditional organisation of value chains, many actors are looking for new types of partnerships outside their own industry. On approach that has been attempted is collaborative innovation, but this has been shown to be difficult for different reasons. Firstly, firms from different industries have difficulties understanding each other in terms of organisations and markets, their respective challenges, and solution space, which leads to lack of trust and large difficulties in establishing partnerships. Secondly, governments, their agencies, and other institutions lack competence in terms of insights and knowledge about these sectors to be able to govern them effectively, industry firms and associations own most of the information and statistics about the industry and report little of it publicly.

Taking a closer look at the innovations examined in REINVENT, we see how knowledge and skill sharing are critical to their ability to scale and build momentum. For instance, existing knowledge on working with bio-based materials within the company was identified as critical for Tierra to develop their bio-based jacket. While competence is generally not massively important in innovations such as zero-waste supermarkets, circulation thereof is fostered by networks of store owners who share their experiences. These kinds of coalition building have also been critical for the zero-waste supermarkets to gain momentum. Spreading an innovation into a new site is however, as we and many others argue, a matter of *contextualisation*, which encompasses developing new knowledge(s) and competences rather than simply implementing existing one(s). Similarly, initiating the demonstration project HYBRIT was key in the mobilisation of massive resources for and gathering actors behind fossil-free

production of steel. As such, pre-existing competences – such as knowledge, skills and coalition building – are important in order for innovations to scale and gain momentum, but these capacities also *emerge through* those very processes.

3.2 Legibility

The emerging discourse of 'net zero' targets for state and non-state actors over the period of the project has increased the relevance and visibility of the material and carbon intensive sectors of the economy and their role in the transition over the period since the project started. In particular, we have seen a growing attention given to the *food* (particularly meat) and *steel* sectors as critical if ambitious targets for decarbonisation are to be realised, though there remains relatively limited attention on *plastics* and *paper*. Although some sectors are receiving more attention before, we nevertheless see a general low legibility of the carbon-intensity in the heavy industries studied in REINVENT, which is linked to earlier raised points about their taken-for-granted materialities. Although steel, plastics, and paper are omnipresent in modern economies and lifestyles, they are highly invisible, or at least unnoticed by most people and excluded from the debate about our ways of living. As such, few people are aware of how much steel or plastics they consume per year. Moreover, the carbon footprint of these materials is rarely communicated or flagged. When these materials are questioned, if so, it is commonly done on grounds other than carbon intensity. Paper, for instance, is mostly scrutinised in relation to deforestation and negative impacts on biodiversity and we rarely see recycled paper being marketed as low carbon. Plastics is mainly problematised through marine pollution and litter rather than through its fossil origin. Such down-stream focus may explain why plastics within clothing has remained invisible despite recent politicisation of plastics. Comparing meat and dairy, meat has a different presence than milk. While the carbon content of both meat and milk has come to foreground, the ability of milk (as milk, as power, as protein etc.) to be part of a range of other products make dairy more omnipresent and invisible.

To this backdrop, it might come as no surprise that making visible through politicisation is crucial for innovations to (re)scale and build momentum. Constructing visions of possible futures around which actors can gather serve to mobilise support and resources, but also make decarbonisation feasible. Innovations that have been successful in this matter (e.g. HYBRIT, Oatly, zero-waste supermarkets) have created a strong desirability, while simultaneously providing a way to act on (climate change) issues. As noted in the case of HYBRIT, the pilot-project has served as a way to align various actors (Vattenfall, SSAB, LKAB) behind a fossil-free steel imaginary and also provided a way to work towards this zero-carbon vision. Similarly, but at a different scale, our examination of Oatly suggest that consuming oat-based products has come to linked to 'planetary stewardship', and thus viewed as a way to advocate for a less carbon-intensive dairy industry, or even world. This suggest that cultural impact is dependent on legibility and political salience. However, this can also be seen as a matter of innovators ability to connect their business models to salient topics. Zero-waste supermarkets, for instance, became about plastic pollution when that issue grew in importance. Similarly, Oatly went from linking their solution to lactose intolerance to climate change, when climate and environmental concerns gained momentum.

Making an issue visual does however not necessarily translate into practices in alignment with decarbonisation visions. BREEAM, for instance, have been important in the making visible of carbon in construction, while it remains unclear if the schemes actually direct decarbonisation practices. Neither does it mean that such goals are translated into people's every day practice. Our work on momentum instead suggest that for goals in alignment with sustainability visions to become fully normalised, they most become taken-for-granted to the extent that they appear invisible. Here Oatly serve as an illuminating example, since they have succeeded to make their oat-based products similar to their dairy counterparts (in terms of colour, packaging, function etc.) yet different (being plant-based, low carbon, etc.). Zero-waste supermarket instead, we suggest, struggle to become a part of people's everyday life, not despite, but just because they are made visual as significantly different from conventional retail.

3.3 Authorisation

The authority to define the problem and its solution space remains a key and contested issue. By employing a value chain perspective in RENINVENT, we see that actors in different positions in the value chains frame (partial) solutions very differently. The plastics value chain is focusing on recycling as the panacea to most of their problems. Such an approach includes decarbonisation, but only addresses it indirectly. By contrast, the DuraSense biocomposite – an innovation deriving from the pulp and paper value chain, but seeking to substitute a variety of plastic articles such as toys, kitchen utensils, furniture, and automobile components – is framed as a solution to minimise the carbon footprint. Here decarbonisation is addressed directly, while recycling of the biocomposite currently seems very difficult and unlikely.

If innovations are to spread and become normalised, we suggest, their problematisation of the issue they address needs to be seen as legitimate. Innovations that lack authority struggle with contestation. For instance, while plastics is seen as a critical environmental issue, removing packaging is generally not seen as a viable solution. Many policy-makers, retail representatives, and packaging experts instead favour a circular-economy approach, which instead promotes recycling and closed loops of production. As such, the zero-waste shopping is by many seen as an illegitimate way of addressing the plastic issue. Innovations may however survive, or even prosper from, contestations by some if other groups acknowledge them as a viable solution. Oatly's problematisation of the climate issue in the dairy sector has been highly contested by dairy companies, to little surprise since they promote cutting out dairy. However, in contrast to zero-waste supermarkets, Oatly has been able to gain a consensus on the need to (at least partially) shift to plant-based food consumption, and have thus gained some authority. We suggest that these perceptions of authority are very much intertwined with frequent contestation over scale and geography of sustainability solutions. While innovators tend to favour local and small-scale solutions, incumbents often state that such approach cannot provide sustainability at larger scales, why they argue that 'true sustainability' comes from incremental improvements made in existing global operations.

3.4 Distinction

Looking at broader tendencies in the industries under examination in REINVENT, we can identify contrasting trends on the distinction of low carbon qualities. Models operate on the basis that those most desirable fuels, technologies and energy services will be driven by their cost point, but our wider work suggests that the desirability of different kinds of investment opportunities, technological innovations, products or services is also driven by their carbon credentials in more subtle ways.

Generally, innovations with indistinct low carbon credentials are more contested than those who wear there carbon qualities on their sleeve, which in turn shapes their ability to scale and become entrenched. Expert statements and LCAs are very important in setting the terms of debate. As such, innovations whose decarbonising impact is uneasily assessed or calculated struggle significantly more with becoming a part of the new normal. This is the case with zero-waste supermarkets, who are accused of not necessarily being 'greener' than conventional supermarkets. Oatly has been more successful in this matter, even introducing LCAs as critical marketing device and critical communication tool. Their assessments are however not accepted by all: dairy companies have contested their credibility and suggested new ways of measuring climate impact. Thus, LCAs are still contested (especially methodically) and variously interpreted. Moreover, our findings suggest that individual emotional responses and gut feelings seem to direct much behaviour in consumer relations to plastics.

However, we also see tendencies of how innovations' claimed sustainability is linked to other aspects than carbon footprint. This, we suggest, is linked to the fairy invisible carbon footprint of industries and their materials. Having 'low carbon' credentials, we note, is for some innovations not enough to convince consumers and many are therefore seeking to link their innovation to other environmental or health discourses. Stora Enso, for instance, is promoting their new paper plates as both low carbon and 'PFAS free' although PFAS is not a chemical associated with this type of product, simply because the debate about the chemical PFAS has – at least in Sweden – been a prominent one in recent years. Paper in general has been able to gain an image as a green material despite its carbon footprint. The question remains if such an image will sustain when pulp and paper firms move into chemicals and plastics, which may emphasise the paper industry's carbon connection.

Health and loose 'environmental' claims are also being done in the building sector, a major consumer of steel. The voluntary assessment schemes BREEAM have communicated their schemes, who explicitly have an environmental focus, as 'sustainable' rather than 'low carbon'. Despite being widely contested for having unclear 'green' credentials, BREEAM has been able to spread significantly. This suggest that the inability to be distinctly 'low carbon' is not necessarily hindering scaling, although it is questionable whether this leads to any decarbonisation change. One may, however, argue that although BREEAM schemes lack 'low carbon' credentials, they have the potential to normalise the idea of regulating carbon in construction, which in a later stage may serve to make (mandatory) environmental standards more easily accepted (see Tozer 2020). Apart from environmental assessments, we also see a proliferation of certification schemes seeking to assess 'wellbeing', often implemented as complementary to the former. There is also a current trend in the timber industry to focus not necessarily on the low carbon potential of using timber, but instead on other features such as their 'naturalness' and potential contribution to occupants' health and wellbeing.

Similarly, Friesland Campina's issuance of a green Schuldschein did not focus on making 'low carbon' qualities of the initiative distinct, but rather focused on a holistic approach to sustainability. The projects financed through the Schuldschein was assessed by a Second Party Opinion following the green bond criteria, and were thus evaluated by their 'environmental benefits', although these were not required to be quantified. Friesland Campina argued that communicating their products as 'low carbon' were unlikely to gain traction among end consumers, especially in a Dutch context where there has been a recent expansion of 'sustainable' forms of milk, such as organic milk, biodynamic organic milk, and weidemelk (free-range milk). Similar tendencies have been identified in the case of Oatly, in which we see how dairy companies have responded to the oat-milk company's low carbon claims by emphasising positive environmental impacts of livestock; how grazing preserves pastureland and thus positively impact biodiversity. This suggest that there is a broader tendency within dairy to communicate other environmental aspects over low carbon qualities. This needs to be seen in the context of the dairy industry's decarbonisation challenges related to the high proportions of emissions being released at a farm-stage.

Thus, although it appears to be critical to be seen as 'sustainable', this does not necessarily mean being distinctly low carbon. However, when this is the case, being seen as low carbon is often perceived as not being enough.

3.5 Reflections

When reflecting on the role that capacities play in shaping decarbonisation change, it becomes clear that these are indispensable in order for transitions to take place. We also see that rather than being separate criteria, these capacities overlap. For instance, the capacity of authority is a condition for the ability to make innovations' low carbon qualities distinct. As mentioned above, LCAs and quantifications has come to be a dominating approach towards evaluating climate impact, which has gained authority. Thus, innovations seeking to be distinguished as low carbon (e.g. zero-waste supermarkets) struggles to be seen as distinctly low carbon. Distinction in turn depend on legibility. If the carbon-intensity of a certain sector or innovation (e.g. paper) is not acknowledged, then it is hard to communicate low carbon qualities of alternatives (e.g. recycled paper).

A key insight of REINVENT is that innovations' ability to bring about (decarbonisation) change can be examined through the concepts of (re)scaling and momentum. As we have seen, all four capacities are critical to these two processes of change. The need for competency in terms of skills and knowledge is particularly important in scaling, since knowledge-sharing is deemed crucial for innovations to scale. Legibility is key in both rescaling and momentum, since politicisation drives contestations of meaning, but also normalisation of innovations. However, although making visible is important for innovations to be acknowledged, if they are to become durable and normal, they must also become taken-for-granted and invisible. The importance of authority particularly manifests in scaling processes, since scaling processes by and large are centred around framing and problematising of issues. Distinction is not necessarily critical capacity for the spread of innovations, but remains critical in momentum, reflected in the cognitive capacities of communicating potential innovations. A key insight deriving

from analysing capacities through the lenses of these analytical concepts, has been that capacities do not necessarily exist as prerequisites for momentum building and scaling, but that they also emerge through those processes.

Moreover, the 'whole economy' approach of the framework appears to have opened up new spaces for investigation. We have examined production-based as well as consumption-based innovations. The former type of innovations, commonly encompassing technological replacements and efficiency improvements, represents a high potential for decarbonisation by 2050. However, due to, GHG emissions are expected to decline first by 2030. Scenarios on consumption-based innovations represent a lower potential on full decarbonisation by 2050, however they have a potential to unlock more early-on decarbonisation through their effect on demand. The literature by and large focuses on production relations and technologically-driven innovations. Seen in this light, our findings on the potential of consumption-based innovations represent a key contribution in this matter. Although not always explicit, it is possible that these advancements are an outcome of the REINVENT frameworks 'whole economy' approach.

4. Conclusions

When revisiting the REINVENT framework, we find many indications that it has served to broaden the understanding of socio-material dynamics of transition. Taking a 'whole economy' approach has been key in this endeavour. With such a perspective, we have been able to expand our analysis to the less scrutinised relations of consumption, while also taking production-relations into account. This has allowed an analysis throughout the value chain, which has resulted in a more nuanced understanding of, for instance, shifting roles for different 'agents of change' and well as how materialities can be made visible/invisible. The highly differentiated politicisations of plastics within retail (packaging) compared to textile (clothing) remains an illuminating example of how the dynamics of inertia and innovations have to be foregrounded *throughout* the value chain and contextualized within their particular relations of both consumption and production. Another contribution of the framework concerns understanding the socio-material dynamics of transitions as being shaped by different agents of change, power, materialities and geographies. It thus becomes more clear why there are particular inertias in some socio-technical regimes, while other regimes are characterized by emerging and ongoing contestations.

The framework has also allowed us to make advances on the understanding of low carbon interventions and their (dis)ability to pave the way for decarbonisation. Analysing low carbon innovations' potential through (re)scaling and momentum has broadened conceptualisation of how these are involved in change-making, but has also shown that innovations' influence stretches beyond their own 'success'. Innovations that 'fail' to scale or become normal nevertheless have the ability to politicise certain issues, and with this instigate conversations or set the agenda within regimes. Through the lenses of these analytical concepts, we note that capacities are not necessarily prerequisites for scaling and momentum building, but also something to be developed through these very processes; when resources, skills, authority are pre-existing they tend to foster scaling and momentum, but these capacities can also be mobilised or created as innovations are being accomplished. The 'whole economy' approach has been helpful also in understanding the potential of low carbon innovations. The different ways in which problems are formulated (plastics in clothing and packaging) and the ability to build trust across sectors, we suggest, are highly linked to value chain relations. Moreover, this approach has opened up to analysing the decarbonisation potential of not only production-based innovations but also consumption-based ones. Since the literature on this matter tend to focus on production, our expanded focus on down-stream dynamics, and its decarbonising potential, represents a key contribution. We cannot say for sure, but it is however possible that this is a result from the framework's 'whole economy' approach.

In each of the two parts, the REINVENT framework has served to acknowledge new dynamics of decarbonisation, while simultaneously taking previously identified mechanisms into account. The result is a broad painted picture of how actually existing forms of decarbonisation is accomplished, and how further potentials, taking both persistency and contingency of regimes into account, can be realised. As such, the framework allows investigation of how large-investments is shaping long-term

possibilities of technological shifts, but also facilitates close-up investigations of how, if, and why certain innovations become accepted as normal when having the opportunity to be initiated. Our findings suggest that understanding the dynamics of decarbonisation cannot be a sole matter of identifying available technologies and their immanent technological capacity, and neither be merely a work of close-up examination how emotional attachment to fossil materials create reluctancy towards low carbon substitution. Instead, the strength of REINVENT's theoretical framework has shown to be including a broad variety of mechanisms through which decarbonisation dynamics is directed, alongside a set of tools through which they can be mapped.

5. References

Bauer, F., Bulkeley, H. Ericsson, K. Hasselbalch, J., Eriksson Lagerqvist, D. Nilsson, L. J., Nikoleris, A., Graham Raven, P., Raymer, C., Romeling, A. Bengtsson Sonesson, L., Stripple, J., and van Veelen, B, 2020. Scaling theories of change in REINVENT case studies. Project Deliverable 6.1, H2020 REINVENT Project Nr 730053.

Bouzarovski, S. and Haarstad, H., 2018. Rescaling low-carbon transformations: Towards a relational ontology. Transactions of the Institute of British Geographers, 44(2), pp. 256–269.

Bulkeley, H. and Stripple, J. Analytical Framework: Rethinking the dynamics of inertia and innovation. Project Deliverable 1.3, H2020 REINVENT Project Nr 730053.

Bulkeley, H. and van Veelen, B., 2020. Financing net zero: How can investment meet the climate challenge? Royal Geographical Society–IBG, London. Available at: https://www.rgs.org/geography/advocacy-and-impact/impact/financing-net-zero/downloads/rgs-ibg-financing-net-zero-report-2020.pdf/

Bulkeley, H., Eriksson Lagerqvist, D., Graham Raven, P., Romeling, A, Stripple, J., and van Veelen, B, 2020. Building Momentum for Decarbonisation. Project Deliverable 6.2, H2020 REINVENT Project Nr 730053.

DNB and PBL, 2020. Indebted to nature: Exploring biodiversity risks for the Dutch financial sector. De Nederlandsche Bank (DNB), Amsterdam and Netherlands Environmental Assessment Agency (PBL), The Haugue. Available at: https://www.dnb.nl/en/binaries/Indebted%20to%20nature%20_tcm47-389172.pdf

González, S., 2006. Scalar Narratives in Bilbao: A Cultural Politics of Scales Approach to the Study of Urban Policy. International Journal of Urban and Regional Research, 30(4), pp. 836–857.

Swyngedouw, E., 1997. Neither global nor local. ‘Glocalisation’ and the politics of scale. In K. Cox (eds.), Spaces of Globalization: Reasserting the power of the local. Guilford Press, New York/ London, pp. 137-166.