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State of the Art Review: Analysing Decarbonisation in the Energy Intensive Sectors

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reINVENT decarbonisation

Contents

1. Introduction: State of the Art Review

The goal of near zero emissions by 2050 has provided a new policy context for energy-intensive sectors such as steel, paper, plastics, meat and dairy. These sectors are central to the European economy and emit several hundred Mton of GHG emissions. Yet in comparison to the energy and mobility sectors, decarbonisation transitions remain relatively unexplored. Energy-intensive sectors are regarded as particularly challenging for decarbonisation transitions. First, the strong dependence of existing industrial processes on carbon-based energy has led to a concern that decarbonisation in such industries will be too costly and threaten their viability. Whilst these concerns are significant, it is worth noting that similar issues were voiced by the fossil-fuel industries throughout the 1990s and (for some) into the 2000s as the emerging global consensus for addressing climate change was resisted (Newell and Paterson, 1998). The increasing acceptance across these sectors and pioneering actions by some leading companies mirror the dynamics of change which have taken place in the energy and mobility sectors as low-carbon systems of provision and consumption have come to be more established. Second, process of global competition mean that any efforts to address decarbonisation in one region may have consequences for the viability of the industry and lead to mobile capital relocating in areas where efforts to control or manage carbon are less rigorous (Morfeldt et al., 2015; Pätäri et al., 2016). Understanding the social, economic and wider environmental consequences of any such transitions is therefore vital in this arena of research.

In order to capture the complexity and potential for decarbonisation in the energy-intensive sectors, the REINVENT project takes a *whole-economy* perspective. That is, it is concerned with the potential for decarbonisation in the 'economies' of energy-intensive sectors from the stages of investment financing (e.g. in how capital is secured to maintain existing production infrastructures or support innovation), resource extraction (e.g. agricultural, mining and forestry processes), production (including many different stages from primary goods to the creation of consumer objects), distribution, consumption (including business to business as well as end-use consumer), and process of waste making and recycling. Important insights can be derived from using the literatures on production networks and value chains for understanding these economies, though this work has been less concerned with the issue of decarbonisation or with processes of innovation. In order to understand these dynamics, insight is also needed from studies of *technological and social innovation* and the forms of *climate governance* that are emerging within and beyond nation-states as part of the response to the ambition for deep decarbonisation.

Our aim is to understand both the extent of *inertia* in the energy-intensive economies and the potential for *innovation*. Reflecting the broad interdisciplinary basis required to understand the challenge of decarbonisation, our approach is deliberately broad. Inertia can be understood in political, economic and technical terms – capital assets and their depreciation are interwoven with institutional systems and everyday practices that create stability around these economies. Innovation is taking many forms, from technological developments, to the creation of 'niches' within dominant regimes, forms of social innovation and grassroots projects, to policy and governance innovations. There is a rapidly growing but highly diffuse literature examining each of these different kinds of innovation. Despite all of the different ways in which innovation is defined across these bodies of work, at their core these analyses are concerned with the ways in which *interventions* are taking place – deliberate attempts to change existing systems. These interventions are characterised by an *experimental* quality (of trial and error, learning by doing) and *novelty* in particular contexts and conditions.

In this state of the art review, we provide an overview of the extent to which the research community has engaged with this challenge. As there is no one field of research from which this challenge is being addressed, it can be viewed as a transdisciplinary research problem where the knowledge required to advance our understanding and create the solutions required for deep

decarbonisation is dispersed between the sciences, social sciences, humanities and practitioner communities. In this review, we draw on five bodies of work – studies of socio-technical transitions, technological innovation, scenarios and integrated assessment, climate governance and value chain analyses - to map the current knowledge base and provide an assessment of the key areas where new contributions are required to advance our understanding.

In the second part of the report, we set out the methodology used for the review. In the following section, we examine how the literature reviewed conceptualises the dynamics of inertia and innovation. We find there is broad agreement that the conditions of *political economy* are critical in shaping the possibilities and limits for decarbonisation. In particular, the literature points to three inter-related dynamics – the relation between state and capital, between systems of production and markets, and between investment/risk and infrastructures – as creating different forms of political economy within each of the energy-intensive sectors reviewed. The fourth part of the report turns to the different kinds of intervention identified in the literature as central to decarbonisation – technological innovation, niche-regime dynamics and governance initiatives. It compares these different approaches and considers how they conceptualise intervention, the factors that shape the extent/effectiveness of interventions, and their limitations. The final section of the report summarises the ways in which we might advance our understanding of decarbonisation by focusing on identified gaps in the literature concerning the agents of change, the nature of power, materiality, geographies of decarbonisation and moving towards a system perspective.

2. Approach and Method

The method adopted for the literature review can be broadly described as a meta-analysis, in which all of the research teams involved in the project focused on a particular field of research and/or sector and systematically applied a series of review questions. Articles were chosen for review on the basis of a key word search, which given the importance of grey literature in this domain included both Google Scholar and Scopus search engines. Once lists of potential articles were generated, the selection of specific articles to review in detail was undertaken on the basis of the extent to which the topics of inertia, innovation and decarbonisation were covered in the articles (according to review of abstracts) and to ensure that a variety of articles across each sector, covering different elements of the value chain, different geographical contexts and forms of intervention were included.

Two of the reviews focused on the *general* literature concerning decarbonisation, one of which focused on studies of socio-technical transitions (24 articles) including articles with a particular interest in issues of policy, markets and geography and the other of which focused on governance initiatives for climate change and sustainability in value chains (28 articles). Four reviews were conducted on the literature concerning innovation, sustainability and decarbonisation in each of the sectors. This entailed a review of 13 articles which applied innovation/transitions concepts to the food sector, along with 19 articles looking at specific interventions related to the meat and dairy sectors.

On paper and pulp there were eight papers including technology assessments, evaluation of the impact of ETS, and historic accounts of transitions in the pulp and paper industry away from oil as a fuel. Seven papers on the steel industry were analysed, several of which dealing with energy efficiency technologies and the implementation. Other papers were about materials efficiency and recycling. Deep decarbonisation is a relatively new idea for the steel industry and the literature is mainly about mitigation options with marginal emission reductions. On plastics there were five papers and topics ranged from the role of alliances in creating legitimacy to LCA of a non-fossil feedstock for plastics. The need for new business models was a topic in one paper.

The paper industry has examples of transitions away from oil made possible through energy efficiency and fuel switching to accessible bio-waste products. Reduced oil-dependence has been a more important argument than climate in those historic developments. Alternatives to coal and coke and deep decarbonisation, other than through CCS, in the steel industry is a relatively new idea not yet reflected in the literature which is geared towards energy and materials efficiency and various mitigation options for marginal emission reductions. For plastics there is a long-standing interest in bio-based and biodegradable plastics which is partly driven by general sustainability concerns and waste problems rather than deep decarbonisation.

The fifth review focused on 27 scenario studies, most of which were on steel (14). The high number of scenario studies on steel clearly indicates that this sector has by far achieved the most attention. The studies included both reports (grey literature: 11) and peer-reviewed papers (16). The reports mainly consisted of national and European roadmap studies. The studies differ with respect to regional focus, from global (with world regions), to European and national level. Table 1 provides an overview of the different kind of studies (in brackets is number of peer-reviewed studies). The table shows a relatively high number of peer-reviewed studies at the global scale.

Table 1: Distribution of the Scenario Studies Reviewed by Scale and Sector

	Steel	Chemical	Paper	Food	Total
Global	5 (5)	3 (2)	0 (0)	4 (3)	**12 (10)**
European	4 (1)	1 (0)	1 (0)	0 (0)	**6 (1)**
National	5 (4)	1 (0)	2 (1)	1 (0)	**9 (5)**
Total	**14 (10)**	**5 (2)**	**3 (1)**	**5 (3)**	**27 (16)**

3. Understanding the Conditions for Stability and Change

3.1 Political Economies of Decarbonisation

Much of the literature, often implicitly, adopts a broad *political economy* perspective for understanding the dynamics of stability and change. By this we mean a perspective that foregrounds the importance of historical processes, structural forces, political factors and institutions in shaping economic outcomes. Even where there is a focus on questions of agency and innovation, in the background to many of the papers surveyed is a concern with the structural limits of that agency. Originating in Rosseau's 1755 as being concerned with how a country—the public's household—is managed or governed, today political economy is a concept that is concerned with the manifold relations between capital and the state. It is the interrelation of trade, finance, production and consumption that have generated the *current carbon-lock in*, and in turn created the terms upon which states and corporate actors engage in a low carbon transition. The extent to which it is possible to realise innovations towards a low carbon economy (REINVENT Decarbonisation) needs to be understood and assessed against this impasse. In particular we can single out three political economy dynamics through which the literature seeks to find explanation for the conditions of stability and change in relation to decarbonisation: (a) the relationship between state/capital, (b) supply/demand (structure of the value chain); (c) investment/infrastructure.

3.1.1 The relationship between state/capital

Political economy, almost by definition, insists that there is a fundamental relationship between state and capital that needs to be taken into account (Gilpin and Gilpin, 1987). From the perspective of liberal political economy, the question is whether effective governance of decarbonisation needs more state-based policies or more market-based policies, or any form of combination thereof. In the critical tradition of political economy, our high carbon presence is the result of, and organized by, existing alignments of states, social forces, and international institutions. Hence, what comes to the foreground here is the processes of production and consumption that contribute to climate change. Both in the liberal tradition and in the critical tradition, there is an emphasis on the close relationships between the regulators and the regulated (Newell, 2015). Research has e.g. highlighted the role of entrepreneurial leaders, and how certain forms of interventions are seen as viable and legitimate as the means through which change in existing systems can take place (Descheneau and Paterson, 2011).

From the perspective of political economy, decarbonisation is contested because it threatens the world's most powerful states and corporations. There is thus an immense structural power to those companies who currently supply the energy and the resources to state elites. The close historical connection between the energy intensive industries and the state has meant that those industries have been able to articulate their interests as consistent with 'the public interest' of a region or a country. A previous CEO of Volvo, Pehr G Gyllenhammar, articulated such sentiment in a well-known motto: 'what is good for Volvo is good for Sweden'. The close alignment between the state and capital is key for understanding the stability/inertia of the high carbon world, and the potential for an intentional transition to a low carbon world.

Approaches from *political economy* have been particularly insistent on articulating globalization as a terrain upon which decarbonisation evolves, shaping the menu of policy options and the autonomy of states to respond in particular ways. The globalised neoliberal world economy becomes a constraint. When faced with the possibility of interventions, industry's threats of capital flight and the relocation of investment, becomes an obstacle to the transitions to a low carbon society. Often framed with a question of 'carbon leakage', the idea that regulating carbon in one part of the world means polluters relocate to unregulated areas of the world, tends to permeate all discussions on decarbonisation (Newell, 2015: 28). The resource-based economic sectors that this report focuses on (steel, forest, plastic and meat/dairy) are all subject to international competition.

But globalisation is not only seen as a 'constraint', but an opportunity for change. There is an emergent conflict between two forms of capital, finance capital and productive (fossil-fuel based) capital. Finance capital has called for a sensitization of the risks of climate change, and the risks associated with continued investments in fossil fuels ('stranded assets'). This fissure has been explored by actors such as 'Carbon Disclosure Project' and 'Carbon Tracker' that help to reveal the risks of an investment portfolio, or even whether investments currently viewed as assets are rather liabilities. A political economy approach foregrounds the social forces and the coalitions (including labour and social movements) that will be needed to decarbonize resource intensive industries, and increasingly examines how different private corporations are becoming involved in decarbonisation. New coalitions of interests, and of the willing, need to emerge. At the moment, 'the winners are politically weak, fragmented, not mobilized or unborn' (Newell, 2015: 33).

3.1.2 The organisation of supply and demand (structure of the value chain)

Research on the structure of particular value chains has been a particularly fruitful way to address conditions of stability and where change might emerge. Rather than thinking about 'steel', or 'meat'

as a sector governable as an entity, the value chain perspective account for the multiple scales at which governance might occur. Concepts such as 'global production networks' and 'global value chains' are approaches to capture the sequences of tangible and intangible value-adding activities. Such approaches typically identify (a) the process of transforming raw materials into final products, (b) the geographical distribution and relations of value-adding activities, (3) a governance structure which explains how the value chain is organized and controlled and (4) an institutional context in which the industry value chain is embedded (e.g. Gereffi et al., 2005). The idea of value chains draw attention to the full range of activities that firms perform to bring a product or service from its conception to end use, including research and development, design, production, marketing, finance, distribution and support to final consumption and waste (Manda et al., 2015).

The value chain perspective also offers the opportunity to better understand options to reduce emissions through investment in innovative process technologies, as well as increased control of energy-intensive materials across the whole supply chain through initiatives to improve resource efficiency, and options to handle carbon leakage risks. Research has shown how so-called 'lead firms', i.e. particularly powerful or resourceful companies, orchestrate the organisation of a value chains resulting in specific allocations of resources and distributions of gains along the value chain (Ernst and Kim, 2002). Furthermore, it focuses extensively on processes of upgrading, understood as strategies and activities that move firms (but also regions or countries) to higher value activities and help them to increase the benefits from participating in a value chain (e.g. in terms of profit, access to capabilities or less pollution). Often upgrading is underpinned by various kinds of innovation activities.

3.1.3 Capital Investment and Infrastructure

A broad political economy approach is a useful starting point understanding stability and change in relation to investments (for example in new production facilities) or in terms of the infrastructure that conditions what is possible to do in a relatively short time frame for a particular company. The importance of economies of scale in the industries implies that investments are very large, which make the firms very cautious. The capital intensity of the industries hinders innovation and sustains inertia. Since the payback period of an investment are so long, change happen only when there is a large certainty that the investment will pay off. On the production side, innovation comes from investment in a new process, a new line of production. The material infrastructure of the process (e.g. land, forest, the cracker, the process plant, the steel oven) creates particular inertias. There are high up-front investment costs, which cause a long-capital lifetime.

3.2 Understanding Inertia

It appears that three general dynamics, of state/capital, supply/demand, investment/infrastructure, alongside the particular structures and interdependencies of resource sector value chains/networks, and the cultural norms and material flows through which they are produced, can be regarded as critical in shaping inertia in each of the sectors with which REINVENT is concerned.

3.2.1 Relationship between the state/capital

It is important to realise that the materials that the REINVENT project focus on; steel, wood, plastics, meat and milk have strong historical and political connection to the place (city/region/state) where they are produced. The sector is thus understood to be tied to the economic prosperity of the region/state, such as steel and paper in Sweden, steel in Wales, petrochemicals in the Netherlands, meat/dairy in parts of Spain/Italy etc. In the cases where this historical interdependence becomes forged at the level of the state, particular strong inertias emerge. There are thus high levels of

interdependence between the state and the sectors, which are seen as key to the economy for providing jobs, growth etc. Jessop (e.g. 2007) has in a series of publications showed how the power of the state stems from its ability to act and relate to these industries in a strategic way. Jessop conceive of the state not as a fixed entity, a neutral coordinator of different interest (social, economic), but shows how the state is formed *through* these wider relations to capital. So while the sectors depend on the state, the state also depends on the longevity of those sectors.

In our survey of the literature, we came across many facets of the relationship between the state and capital. Long et al. (2016) points out that the diffusion of innovations is hampered by inconsistency in policies between different countries and regions, between national and EU levels, as well as over time (particularly in relation to carbon pricing). Hellsmark et al. (2016) argue that risk of investing in biorefineries (which is a large scale undertaking) is conditioned by uncertain policies. Similarly, Coenen et al. (2015), discussing renewable energy transformations, argue that 'government policies are providing unclear and contradictory signals concerning the needs for carbon reductions' (Coenen et al. 2015: 859). Klitkou et al. (2015), studying energy and road transport, argues that in Denmark the lack of automobile producers means little influence on standards for electric vehicles and suboptimal charging practices. In Norway, lack of a strong domestic industry means there is little support for ongoing research into hydrogen and FCEVs at public research organizations. In Norway and Sweden, the economies of scale in oil/gas and energy production have disincentivized investments in hydrogen and advanced biofuels. During the recent financial crises, there were green stimulus packages that initially spurred investment in green transitions. Geels (2013) however point out that these came to an end. Austerity and changes in public and political priorities (i.e. focusing solely on economic issues at the expense of environmental concerns) led to a weakening of climate and sustainability policies. To Pearson and Foxon (2012) the fundamental issue is that a move from our contemporary high carbon industrial lock-in cannot be achieved through basic economic substitution. The transformation needed will be much more systemic and profound.

3.2.2 Supply/demand and the structure of the value chain.

Despite wider relations between the state and capital, many papers on the sectors draw attention to how 'internal factors' are more important than external factors in shaping the conditions of inertia. The argument is that inertias in the production of steel, paper, plastic and meat & dairy can be understood as emanating from drivers that are internal the production process itself. This is however a result that stem from papers focussing on the supply-side. Papers that look at the demand/consumption side; how and where steel/plastic/paper/meat/milk is consumed take a host of external factors into account. Many of the interventions (innovations, certifications, codes) that we are looking at shape/reshape the consumption of materials (how is a house built, how food is packaged, how clothes are made, what we eat). But when trying to get rid of the carbon (either through new production processes or through alternative forms of consumption), inertia is (across the sectors), produced through concerns about the quality of the product. Decarbonisation is understood as a risk to a particular quality of the product, leading to an overall failure of the product.

The materials that REINVENT work with have a host of properties that are worth noting. Steel has a host of properties that seem to require integrity. Steel is strong, while still being malleable. Steel is magnetic in many senses of the word. Innovations in new (low carbon) processes of steel production will face the question of quality, and concerns about quality create particular inertias. For plastic, new kinds of plastics need to have the same attributes that the old/normal ones have. There is the risk that by producing a new 'low carbon product', the value of the normal product will be devalued. Is, for example, 'bioplastics' the right kind of plastic? Or, if the plastic is produced through biomass and is degradable is it still plastic or is it 'paper'? Inertias are here conditioned by the concern for not knowing the quality of the new product. In relation to the question of quality, is the question of

'distinction'; there is not enough distinction between different kinds of products, hence consumers cannot make 'the right choices'. For example, consumers are not being able to distinguish between 1st and 2nd generation biofuels (Coenen, 2015), or between different forms of plastics.

A key insight from the review of the papers is that the structure of the value-chain produces particular inertias. Markets are shaped by big companies with direct control of large parts of the value chain. Dewald and Achternbosch (2016) study of 'why sustainable cement has failed' is a case in point. Up- and downstream integration raises entry barriers in the industry, creating oligopoly, frequent cartels, and standard making controlled by incumbent industry. Forest companies (in the Nordic countries) both own forest and produce forest products. Large food retailers shape the production of particular commodities, and while some petro-chemical industries (such as Borealis) buy the feedstock, they own both the cracker-plant and subsequent plants for producing particular plastics. These conditions shape inertias, in particular when different forms of circulation do not align. An example is the competition between the plastic industry and forest industry about who will capture the value chain. The plastic industry needs the 'bio-feedstock', but the forest industry does not want to be a supplier of raw materials; they want to develop 'the products' and capture that part of the value chain. So inertia in plastics is perhaps produced through 'lack of supply' and the circulation of materials is not that easy to divert. Geels (2013) makes the point that incumbent interests provide active resistance and lobbying with the aim of hindering institutional change toward more environmental sustainability.

In the review of the papers, we found papers that dealt with the cultural constitution of different kinds of demand. In Norway, for example, the share of passenger transport by passenger car is highest in all the Nordic countries (87.7%), meaning that societal norms greatly favour private vehicle use. Inertias are thus reproduced through cultural expectations (how should a house look like? What is a small car? What is a healthy meal?) and in the everyday normalisation of material uses. Overall, we found more papers that discussed the cultural political economy of meat, milk, plastics and fewer that dealt with steel and paper.

3.2.3 Investment/Infrastructure

A broad political economy approach is a useful starting point understanding stability and change in relation to investments (for example in new production facilities) or in terms of the infrastructure that conditions what is possible to do in a relatively short time frame for a particular company. The capital intensity of the industries hinders innovation and sustains inertia. Since the payback period of an investment are so long, change happen only when there is a large certainty that the investment will pay off. On the production side, innovation comes from investments in a new process, a new line of production. The material infrastructure of the process (land, forest, the cracker, the process plant, the steel oven) creates particular inertias. There are high up-front investment costs, which cause a long-capital lifetime.

Many of the papers drew attention to how the capital intensity and the high up-front costs of investments in the industries condition inertia. The importance of economies of scale in the industry implies that investments are very large, which make the firms cautious (Näyhä and Pesonen, 2014). Dewald and Achternbosch (2016) found, from this perspective, very few (if any) incentives to innovate and decarbonise cement. There is a long payback time for the investments made in production facilities and the necessary infrastructure. The review of meat & dairy finds less emphasis on declining capital costs, but for the dairy industry (in northern Europe) there are large infrastructure investments in keeping the fresh milk flowing through an unbroken cold-chain, from the farm to the supermarket. The review of the steel sector found mixed results on the importance of cost on investment and availability of finance.

The literature suggests that investments in 'energy efficiency' have dominated over questions about 'material efficiency' (how, and where it is used). The process through which a particular material is produced has been highly optimised creating standard operating procedures and sustained by informal knowledge and in-house expertise in particular firms. Inertia is also conditioned by geographical contexts, which shape what it is seen as possible to change and which create local interdependencies, even in the same firm. Inertia is also shaped by risk aversion or through 'fear of losing control'. Brockhaus et al. (2016: 92) argues that 'it is not technological shortfalls or actually higher costs that cause some of the hesitancy to act but rather the fear of not exercising full control over the outcomes of the action'. While the known is controlled, the unknown is uncontrolled. This may explain why approaches such as certification and monitoring work as a means through which change can be enabled, for they do not only provide new *cognition* or knowledge about what is possible but also offer a sense of *control* over new processes or products.

Investments in transitions to sustainability are also shaped by what is happening in society/economy at large. Geels (2013) argues, that the recent financial crisis ultimately had a negative impact on sustainability transitions. After offering a window of opportunity in which the global financial crisis could have positively impacted the transition toward sustainability, the window has now begun to shut, pitting financial-economic concerns against those of the environment.

3.3 Understanding Innovation

REINVENT is interested in why energy-intensive economies stay the same (inertia) and how they might be changed and transformed through intentional interventions. From the perspective of political economy, the review of the literature indicates three general dynamics (state-capital, supply-demand, investment-infrastructure) that seem to condition the possibilities for innovation to emerge. The review also identifies particular structures and interdependencies of resource sector value chains/networks, and the cultural norms and material flows through which they are produced, as critical in shaping innovation in each of the sectors with which REINVENT is concerned.

3.3.1 State/capital

Across the sectors, the relationship between state and capital is seen as key to understand the conditions that shape innovation. It is about the 'ground' and how it is prepared. The state is assumed to provide the conditions within which innovation can flourish. Much of the literature here thus focus on the state and its key role in laying the ground for innovation through making appropriate finance available, creating a level playing field through regulation, or in responding to consumer pressure. For example, in the case of energy transitions, political agreement on energy policy created a space for entrepreneurial experimentation in the form of a national demonstration programme for biofuels in heavy vehicles (Sandén and Hillman, 2011) and the (Swedish) state were very active in developing a strong R&D environment around biorefinery in order to promote regional growth (Coenen et al., 2015). Policy makers cannot assume that a technology will be commercialized once it is fully developed. It is clear that developing the technology does not guarantee its commercialization. Policy makers need to be aware of this, and involve top-level management when supporting R&D projects as a target for learning processes (Hansen and Coenen 2016). Or, as Skellern et al. (2017: 1783) points out, the state must develop a diversified policy approach that enables a fundamental shift towards long-term sustainable change. This requires a holistic analysis within the traditional manufacturing sector of relevant socio-technical characteristics. Hence, in most of the literature the key actors are seen as the *state* (political-administrative systems at various levels) and the *firm* (contrast this with the literature on the governance of innovation for sustainability/low carbon, where the 'agents of change' are cast much more broadly. An important corrective to this

literature which has focused on enabling change is the work that is bringing forward the notion of *creative destruction* – what has to be *un-done* in order to make space for the low carbon transition.

3.3.2 Supply/demand & structure of the value chain

There is also some emphasis on market conditions for innovation – whether demand is being created for alternatives through e.g. consumer pressure, supply chain restructuring/changing demands for end products. While innovation is shaped by changes in demand, the papers show the importance of understanding where the material is consumed. Buildings are a critical site for steel use; so knowing what is happening in the building economy (e.g. new trends for prefabricated housing, the economies of the commercial building sector) is critical for understanding steel transitions. Path dependence, related variety and proximity are crucial in regards to transition of regions. As Skellern et al. (2017) note, for example, while the Pittsburgh region exhausted its steelmaking capacity, it did not lose that expertise, so it translated it into becoming a steel technology cluster.

The structure of the value chain is an important condition for innovation. Since there are key actors that control large parts of the value chain, those actors possess the capacity for innovation and taking more action. For example, the forest company SCA has a massive focus on energy efficiency, which is only partly driven by EU ETS. Hansen and Coenen (2016) points out that knowledge sharing between sectors is key - the pulp and paper industry has insufficient knowledge about the chemical industry and vice versa. But knowledge alone is not enough - pulp and paper firms need certainty for the existence of new markets (purchasing agreement commitments). Yet despite the emphasis on understanding the structure of the value chain, few of the papers deal with how innovation is driven by changes in demand/consumption. The exception is in terms for those papers that focus on meat and dairy. There is a wide discussion on how governance initiatives (not just technical solutions) shape food economies. Carbon footprint labelling has been well covered, including its limited effectiveness, but the literature perhaps overlooks its wider ways of 'working' in the sector/cultural political economy terms. Demand for meat/dairy can also be shaped by 'grassroots' innovation, such as 'local community growing' projects.

3.3.3 Investment/infrastructure

The reviewed literature shows that a critical mass of engaged companies is central to the success of innovations. Companies can capitalize on the presence of and/or relation to one other, in the form of technical knowledge, legitimacy, or physical assets (Sandén and Hillman, 2011), which enable them to develop competencies for branching into new industries by drawing on a recombination of different but related knowledge from previous industries (Coenen et al., 2015). Proximity is key for 'transition regions' to emerge (Skellern et al., 2017). For the biorefineries are partnerships (e.g. joint ventures) with firms from other industries (e.g. energy and chemicals) important for innovation. There is an emphasis on how certain initiatives shape investment conditions that favour innovation. Schemes like 'green certificates' and 'program for energy efficiency' (PFE) change investment risks and put the issue on the agenda.

4. Conceptualising Intervention: technological innovation, niche dynamics & governance initiatives

Interventions, of one form or another, lie at the heart of the process of system change. As discussed in Section 3, various accounts have been given as to how the ground for innovation may be prepared so that such interventions can flourish. Here, we turn more specifically to the nature and dynamics of interventions themselves. Across the wide range of literatures that have been brought to bear on the intersection of climate governance, production networks and socio-technical transitions such interventions are conceived and subsequently analysed in highly diverse ways.

Within the energy-intensive sectors with which REINVENT is concerned, there is a focus on *technological innovation* as a key form of intervention. Technological innovations include the invention, advance or diffusion of a technological production process or product. The dynamics of this form of intervention are seen as primarily shaped by the relation between the state – who should provide the context for innovation – and the firm – who should lead and benefit from innovation, with the market strongly shaping the trajectories of uptake across the sector.

A second approach to understanding intervention has focus on *niche innovations* located within dominant socio-technical *regimes*. In the transition studies literature, such approaches initially focused on the ways in which niches offered (market) protection for (technological) innovations. As the field has expanded, a wider range of processes have come to be recognised in the formation and management of niches for sustainability transitions – including the development of coalitions, shared visions, and learning – and the potential for *social innovations* has also been recognised (Seyfang and Smith 2007), though none of the papers included in this review specifically focus on the nature of grassroots or social innovation.

Within the literatures on climate change and production network governance, the question of how interventions can lead to change comes from a different starting point. Rather than being concerned with the development of *social or technical innovation* per se, this literature is interested in the *governance initiatives* which are taken in order to shape sustainability responses. Such interventions are also sometimes referred to as *governance innovations* (Kivimaa et al. 2017). Here, initiatives are interventions designed to be able to govern in often complex contexts where the relation between the 'will' to govern and direct control/capacity to address sustainability may be distant and dispersed.

This section reviews each of these approaches and the ways in which they understand the dynamics of intervention and system change in turn.

4.1 Technological innovation

Across the literature studied, there is a great deal of attention paid to the promise of technological innovation as a means through which decarbonisation can be achieved. Technological innovation dominates the development of scenarios for low carbon transitions in the steel and plastics sectors, as well as in those papers which seek to understand the options facing firms as they seek to address this issue within their industry. For the most part it is within the *production* process that an emphasis on technological innovation is found, with limited consideration of alternatives (e.g. Fleiter et al., 2012; Wesseling et al., 2017). Although in the literature on plastics there is also an interest in how innovation in the material feedstock (from oil-based to bio-plastics) can take place. The literature also shows a strong focus on technological innovations that produce *energy efficiency* (e.g. Ashrafi et al., 2015; Katajajuuri et al., 2014; Masanet et al., 2014), with relatively less emphasis on innovations related to *material efficiency* or to *material substitution*. Exceptions include an interest in the innovations required for the development of alternative feedstock (e.g. bio-materials for plastics, scrap steel (Morfeldt et al., 2015), changing gene pool in the cattle industry to reduce methane (Hayes et al., 2013), or reducing waste within the feeding process (Banhazi et al., 2012; Zu Ermgassen et al., 2016). Additionally, the literature focuses on the analysis of how choices between/innovations within different production processes have a significant effect on the potential for decarbonisation (e.g. in relation to paper, three different pulp production processes create different carbon outcomes (Fleiter et al., 2012; Ottosson and Magnusson, 2013); in relation to livestock, different production processes create different GHG emissions trajectories (Bellarby et al., 2013)).

The literature on technological innovation places a strong emphasis on the need to create the right conditions within which such technological breakthroughs can emerge. This includes, predominantly, a focus on the importance of the state in setting both creating a 'level playing field' for action amongst competing firms (e.g. by providing strong policy signals and policy stability) (Gulbrandsen and Stenqvist, 2013; Pätäri et al., 2016; Wesseling et al., 2017) and in providing incentives to overcome existing inertia (e.g. subsidises for investment in alternative technologies, R&D support, changing the costs of carbon) (Bergquist and Söderholm, 2016; Fleiter et al., 2012; Gulbrandsen and Stenqvist, 2013; Liu and Gao, 2016). Though some studies also note that 'external drivers', such as policy interventions, have limited effect (Arens et al., 2016). The importance of securing the right form of capital investment is also regarded as central for innovation. To be adopted, technologies must fall within a 'payback window' that is no longer than 2-5 years depending on the industry in question (Fleiter et al., 2012; Liu and Gao, 2016). In the case of the German iron and steel industry 'economics matter'. The results indicate that investment rarely happened at payback periods exceeding about 3 years. Increasing coke prices led to the strong uptake of PCI from 2004 onwards. A better economic outlook of a company also strengthens the uptake of EET (Arens et al., 2016). Other analyses suggest that new kinds of business model are required that can enable the costs of technological innovation to be shared across the value chain, e.g. where the costs of decarbonising steel might be passed on to the automotive industry creating a very minor increase in the overall cost of a car (Rootzén and Johnsson, 2016) or in relation to plastics in order to join up the value chain around bioplastics (Iles and Martin, 2013). A few papers also mention the strength of consumer demands (both direct consumption and business to business consumption) and the growing role of CSR strategies in shaping investment in technological innovation (Pätäri et al., 2016).

Scenario studies tend to assume that given the right conditions ('the egg') it is assumed that innovation ('the chicken') will be largely driven by economic rationality and inter-firm competition, such that it will grow and be taken up widely across the sector. Bottom-up analyses of technological innovation caution against such universalising principles, and suggest instead that the uptake of innovations is likely to be structured according to the conditions prevailing in particular parts of the sector, particular geographical regions, and even down to the firm level.

Despite a strong focus on technological innovation as the means through which decarbonisation might be achieved, the literature suggests that there is limited evidence to date of technological breakthroughs and instead forms of technological incrementalism dominate (Gulbrandsen and Stenqvist, 2013). Given the emphasis in this literature on the role of the state (and capital finance), the solution called for is often one requiring more state-based investment in setting the conditions for transition. Intriguingly, this is the case in relation to bio-plastics, even where the literature points to strong concerns across the industry (and in the upstream production of bio-materials for the sector) about the viability of such a plastic economy. Despite these concerns, the solution to decarbonisation in plastics is re-iterated as one of moving towards more bio-plastics technological innovation supported by the state. Moreover, a focus on technological innovation as the means through which system change can occur has been critiqued for its often simplistic account of how technological change occurs through the introduction of (singular) new knowledge/product innovations which underplays the importance of interactions (and contestations) between multiple technologies and actor coalitions (Sandén and Hillman, 2011). Equally, the underlying assumptions of market rationality and economic decision-making have been critiqued as evidence, which suggests that the presence and economic viability of an innovation is insufficient to guarantee that it becomes commercially viable or mainstreamed within the industry (Hansen and Coenen, 2016). As Coenen et al. (2015) suggests systems change not only through the influx of radical new technology, but also through changing firm routines and institutional adaptation and focusing on non-technical, social learning processes. At the same time, with a dominant focus on a circumscribed part of the value chain/economic circulation – usually the production stage of the process – the wider system

dynamics are often overlooked, and the geographical and material dimensions of transition tend to be neglected.

4.2 Niche-Regime Dynamics

A second main strand of the literature on low carbon transitions in general, and applied to the energy-intensive sectors in particular, are those approaches that seek to analyse the dynamic between what are termed 'niches' (innovations) and 'regimes' (incumbent socio-technical systems). Socio-technical regimes can be defined in broad terms as stable configurations of social and technical components, in which the interests of different actors and existing technological possibilities are aligned through formal rules and informal codes of conduct (Elzen et al., 2004; Geels 2005; Geels and Schot 2007; Grin et al., 2010). Importantly, while regimes are stable, they are also emergent: 'neither centrally controlled nor directed towards a clearly defined goal' (Hughes, 1983: 6). In this context, regimes and innovations are regarded as constituted through the iterative co-evolution of social and technical entities. From this tradition, the multi-level perspective has been developed to explain how niche level innovation can drive regime change (Geels, 2002, 2005; Geels and Schot, 2007). A heuristic model, the MLP identifies the 'landscape' conditions within which the relatively stable socio-technical configurations of regimes are embedded, while the 'niche' (usually emerging outside of the mainstream regime) contains the seeds for disruptive change. If sufficiently cultivated, niches should be able to 'breakthrough' regimes to establish new socio-technical orders that, in this case, create transitions to low carbon economies.

At the heart of this analytical perspective is then the idea that innovation takes place through niches. Niches may emerge through the innovation process or be actively fostered through what is termed strategic-niche management (Kemp et al. 1998). In either case, what is required for the niche to grow and achieve dominance is some form of 'protection' from the existing regime (Smith and Raven, 2012). One significant mechanism offering such forms of protection is that of *shielding*, in which niche innovations are exempted from mainstream market pressures, e.g. Hellsmark et al. (2016) argue for the need for state support for the development of markets surrounding biorefineries). A second form of protection is found in *nurturing*, in which additional support is provided to niche innovations. For example, Farla et al. (2012) found in their work that policy makers and public authorities had a central role in transitions through financing the pre-competitive phase of innovative more sustainable technologies. In the literature on technological innovations discussed in Section 4.1 (even where not explicitly framed in terms of the relation between the niche/regime) these forms of protection are a predominant concern – how the state can create the right conditions within which niche innovations can thrive through either shielding them from mainstream market dynamics or providing bespoke support.

Yet research suggests that the cultivation of niches requires more than simply protecting them from prevailing market conditions – it requires forms of *empowerment* through both internal dynamics that support their development and capacities to change or destabilise the regime (Smith and Raven 2012). This includes a focus on the 'sense-making' agency and generative capacity of niches (Smith and Raven 2012: 1026). In the literature, key processes in the development of niche innovations are thought to include the production of collective visions, the development of social networks, and learning (Frantzeskaki et al. 2012; Frantzeskaki et al. 2014; Raven et al. 2008; Schot and Geels 2008). Such factors are also used to explain how & why niche innovations are able to 'scale up' and become mainstream. Ceschin (2013), for example, finds that the diffusion of radical innovations is highly conditioned by the capacity for niche actors to establish broad networks, create visions, align expectations and undertake reflexive learning.

There is a growing body of evidence that documents the importance of these niche dynamics for sustainable innovation. Soesanto et al. (2016) finds that companies who choose to produce bio-based plastics, tend to do so since where the owners or directors of those companies have formulated a clear environmental vision, which creates the capacity to seek to create a new market share amongst environmentally aware consumers. Farla et al. (2012) find that associative network governance, proximate relations and trust serve to help frame 'collective expectations' within niches around goals which are able to leverage change within the system. There is some emerging evidence that regional economic dynamics, clustering and other forms of geographical relation are important in fostering niche dynamics (Coenen et al., 2015). Mattes et al. (2015) found that innovation emerges through the interplay of the subsystems of a given region: science, politics, public administration, industry, finance, intermediaries, and civil society. Nonetheless, it is critical not to regard such 'geographies of proximity' as the primary influence on the development of niche innovations (Coenen et al., 2015), not least because of the highly globalised and networked nature of the economies of the energy-intensive sector. Niches have also been found to be important in fostering the space for *experimentation* (Farla et al., 2012). For example, Hellsmark et al. (2016) emphasises the importance of pilot and demonstration plants (PDPs) in the development and commercialisation of new technologies, enabling both technical and institutional risks to be minimised. Karltorp and Sandén (2012) found that the state played an important role in providing support for the development of pilot and demonstration plants for new PPI technologies in Sweden.

While it has been the niche that has attracted the most sustained attention in the literature concerning innovation and sustainability transitions, a concern with the nature and dynamics of the regime has perhaps been underplayed. Recent work has attempted to address this balance. First, papers have begun to explore the iterative dynamics between niche-regime (van Amstel et al., 2013). Geels et al. (2016) in a new line of argument suggest that rather than single niches 'out competing' the regime and leading to a transition from one socio-technical configuration to another, the process of change should be theorised as one of 'endogenous enactment' in which shifts between transition pathways occur as the result of shifting actor coalitions, struggles and adjustments in formal rules and institutions. Radical innovations are not then necessarily produced *outside* the regime in discrete niches, but can emerge through coalitions and alliance between new firms, social movements, citizens and incumbent interests. The case of the development of new waste management systems in Manchester bears some of these hallmarks. Triggered by the 1999 Landfill Directive, the local authority was able to actively de-instituted the existing system by divesting their waste disposal firm, re-negotiating the waste disposal levy, separating landfill contracts from the emerging system, and finally withdrawing financial resources (Gee and Uyarra, 2013: 117-118). This case also points to the importance of a second emerging theme in the literature relating to socio-technical transitions – the importance of *creative destruction* (Kivimaa and Kern, 2016). Kivimaa and Kern (2016) find that policy mixes that focus on 'creative destruction' (policies that aim to facilitate the creation of new niches and for the destabilization - or destruction - of old regimes) are key to driving sustainability transitions.

In summary, we can say that while studies of niches of technological innovation are present within this field, this tends to be dominated by a concern with the forms of protection that are required to develop niches (particularly with respect to shielding and nurturing). There are several important exceptions of studies that have examined a wider set of niche dynamics (visions, expectations, networks, learning, regional clustering) in order to understand how sustainable innovations are developed within these contexts. Yet the analysis tends to rest at this level – drawing a cause and effect relationship between the presence of e.g. visions and the development of niche innovations. There is less critical engagement with *how* this causation takes place – what are the properties or the essence of what it is that e.g. visions provide that enable innovation where before such capacities were not forthcoming.

Moreover, some of the wider critique that has been applied to the 'transition studies' approach is relevant here too. Often, the assumption is of a 'national' scale regime, which may be difficult to map against the globalised, value-chain nature of the economic sectors with which REINVENT is concerned. Where questions of geography are considered, these tend to be related to the relatively straightforward matter of (regional economic) clustering, rather than taking full account of the different spatialities which structure and embed different regimes – including what Bridge et al. (2013) have termed territorialisation, landscape, scale and place – or of the complex proximities/absences through which production networks operate (and hence the nature of the circulation/translation of different kinds of innovation within and between actors in any one sector). Equally, despite an avowed interest in the co-evolution of the social and 'technical' elements of socio-technical systems, the latter are often reduced to background conditions or inert entities that have little agency in the transition processes themselves. There is considerable scope to consider materialities as more emergent properties of particular socio-technical configurations and to consider the 'work' that they do in both stabilising and enabling change within particular sectoral configurations (e.g. what the differences between 'real' and 'scrap' steel mean in terms of how particular steel transitions are formed). Finally, concerns have been raised as to whether such perspectives adequately deal with questions of power. Recent writing in this field has proposed, in keeping with the broad direction of REINVENT, that questions of political economy must be put at the heart of understanding of transitions (Geels, 2014). Yet such analyses tend to focus on the power capacities of individual agents (usually a powerful individual, firm or state) rather than the structural conditions through which power is ordered. At the same time, there has been little research that has sought to bring alternative accounts of power that regard it as an emergent property of socio-technical configurations (or assemblages) to bear on the question of the dynamics of transition. This is a potential avenue for further exploration within the REINVENT project. This relates to the finding that there has been limited analysis of the *regimes* through which the inertia of energy-intensive industries is maintained and reproduced. At the same time, given the emphasis on market dynamics within much of the technological innovations literature and the *scenarios* for low carbon pathways, the *processes* through which innovations are mobilised (within sectors, between places) and 'scaled up' require further investigation.

4.3 Governance Initiatives

The landscape of climate governance has radically changed since the initial formation of the first multilateral agreement at Rio in 1992 and initial efforts at policy design at the level of the national government and European Union. In parallel, analytical attention has shifted from these (relatively few) arenas to examine the multiple *initiatives* through which climate governance is now taking place. Research has charted the emergence of transnational, private and urban governance experimentation as a phenomenon that gathered momentum during the early 2000s and has since substantially expanded. At whichever scale, climate governance is characterised by initiatives which use a range of different tools/techniques in order to address climate mitigation – from labelling, certification, monitoring to the development of targets and collective commitments for emissions reductions. This form of governance is also to be found across diverse production networks/value chains where sustainability has come to be a concern, for example in relation to forestry (timber, palm oil), fisheries and some agricultural products (coffee, chocolate, tea, flowers, wine, cotton).

Rather than being predominantly concerned with the *technological innovation* taking place, the literature that has developed to understand the governing of climate change and sustainability across these spheres has focused on the multiple sites and actors involved, the governance arrangements put in place and the techniques/tools through which the stated aims/rationalities of governing are enacted. Although there is limited explicit cross-over in the literatures – those that focus on climate change tend to work with particular governance arenas while those that focus on

particular production chains instead 'follow the object' – there are sufficiently strong similarities that these two bodies of work can be considered in relation to one another for the purposes of this report and for the REINVENT project.

It is important from the outset to recognise that while significant attention is given to the rise of subnational and non-state actors in these forms of governance, this should not be regarded as synonymous with the decline of the state (Jordan et al., 2015). Sustainability governance is not a zero-sum game in which growing power amongst one set of actors leads to the demise of the other (Bulkeley and Schroeder 2012; Boström et al., 2015; Bush et al., 2015). Instead, what constitutes the state/non-state is being reconfigured through these arrangements and arenas. In their recent study of the UK retail sector, Spence and Rinaldi (2014) found a high degree of entanglement and interdependency between the state (as regulator) and the supermarkets, both bound by these regulations and undertaking their own regulatory functions within supply chains in order to meet consumer and regulatory demands for increasing sustainability standards. Bush et al. (2015) argue that rather than regarding sustainability governance in value chains as a matter of private governance – what they term governing *in* or *of* value chains – the emergence of a concern with sustainability and private governance in global production and consumption [studies]… [has identified] arrangements that can be considered 'a political settlement and institution building project' pursued by social movements, international NGOs, private companies and states (Bartley 2010, cited in McCarthy et al., 2012: 564; cited by Bush et al., 2015: 8). This they suggest has drawn analysts to examine how governing sustainability takes place *through* supply chains, which captures the complex socio-technical networks and flows of power and materiality by which governing is accomplished:

> *'Governing sustainability through chains involves a set of normative and regulatory practices that use the chain as a conduit for influencing the social and environmental conditions of production and consumption. … governing through chains is neither understood as firm-level CSR systems, nor as inter-firm coordination. Instead it is a broader level of governance that captures the interaction between the chain and its firm actors with a wider set of networked actors and activities that collectively steer sustainable production and consumption practices'* (Bush et al., 2015 p.13)

The literature on governance through value chains points clearly to a wide range of drivers shaping the growth of interest in sustainability, including an 'increasingly regulated, monitored environment', consumer demands and the potential for the growth of new markets around 'green' products which in turn is driving demand for 'tools and mechanisms to assist the promotion of sustainability within organizations and also within their supply chains' (Spence and Rinaldi, 2014: 4). Specifically in the forest sector, Overdevest and Zeitlin (2012) identify two mechanisms through which governance initiatives have emerged. First, through the campaigning activities of NGOs who put pressure on supply chains from consumers to producers, and persuaded large 'end-of-chain' retailers to adopt new standards which over time 'have become more broadly institutionalized as good business practice' (p.18). Second, private certification has expanded and developed 'as an alternative to the weak public international forestry regime … [through] horizontal diffusion within industry associations'. (Overdevest & Zeitlin 2012 p.19).

Similarly the climate governance literature identifies the growing malaise surrounding the multilateral regime during the mid-late 2000s as an important driver for the uptake of alternative governance initiatives, as actors sought to step into fill what was regarded as a governance void (Hoffmann, 2011; Bulkeley et al., 2014). At the same time, governing climate change has come to be accepted within (some sections) of the economy as a matter of good business practice, while cities and communities have also sought to benefit from the co-benefits of climate governance initiatives. For both climate governance and the governing of value chains, these twin dynamics of a 'void' of

governance capacity (at the international scale, by the state) coupled with an increasingly normalised position that action on sustainability is both a responsibility and an opportunity have served to drive a whole array of governance initiatives. Yet this proliferation has created a complicated governance landscape – frequently referred to as a 'regime complex' – coupled with a seeming fragmentation of authority to govern, which may create 'forum shopping' as individual actors move to more favourable (private) regulatory contexts (Overdevest & Zeitlin 2012). Such an argument underplays the value that actors find in responding (effectively) to climate change/sustainability, but is nonetheless an important consideration.

Having established that governance initiatives are now widespread in many arenas of climate governance and within some value chains (notably those related to food, fisheries and forests), the literature identifies two primary forms of intervention – those based on *conflict* and those rooted in *collaboration*:

> '*Organizations are pressured by consumers, NGOs, other firms and even governments to reframe their conceptions of responsibility away from a narrow national mind-set and beyond their own organizational borders. These pressures have been manifested both in conflict (e.g. name-and-shame campaigns and consumer "boycotts" targeting big brands) and in the pro-active development of multiple institutional and regulatory innovations for "sustainable supply chain management", including eco-labels, codes of conduct, auditing procedures, product information systems, procurement guidelines, and eco-branding.' (Boström et al., 2015: 2)*

Within the climate governance literature, a similar distinction can be made between social movements and NGO campaigns that have sought to put pressure on state/non-state actors, and the kinds of collaborative arrangements, partnerships and initiatives through which collaborative forms of governance are developed. In each case, the techniques used as the mechanisms through which governing is realised are similar.

Firstly, techniques of contestation include campaigns by NGOs which target particular products, companies and consumer groups, seeking to publicise negative environmental impacts and call for boycotts (Dieterich and Auld 2015: 54). Such campaigns have become a central part of forest politics, for example, such that several US philanthropic foundations became key funders of groups working to transform practices in the forest sector. Over the course of the late 1990s and the 2000s, this has included campaigns against the home retail sector (e.g., Home Depot), the office supply sector (e.g., Staples), the catalog industry (e.g., Victoria's Secret), and major financial institutions (e.g., Citi Group) (Conroy, 2006). 'In each instance, these buyers and financers were targeted with the aim of having broader influences on the upstream practices of forest products companies' (Dieterich and Auld 2015: 54). Evidence for the role of such campaigns is also found in the UK, where 'pressure from Non-Governmental Organisations such as Friends of the Earth and the WWF has been exerted on the Milk and Beef sectors through the commissioning of critical reports that advocate radical changes in production' (Mylan et al., 2015: 23). The nature and impact of such campaigns and their effect on the EU PPI may be an important focus for research for REINVENT. A second set of techniques through which governance initiatives seek to contest existing socio-technical orders are through forms of social movement/mobilisation. The 'Meat Free Monday' initiative is of this kind, rather than target specific organisations, it seeks to work through multiple sites and communities to achieve social change by contesting the existing predominance of meat in western diets (Morris, 2016). A third set of techniques involves seeking to act on a particular set of actors – financial investors. Most recently evident in the fossil fuel divestment movement, these targeted campaigns tend to work not only through public arenas but also through the development and use of tools that seek to make the nature of current patterns of investment visible and calculable, such as forms of monitoring, certification and standards.

Voluntary standards and certification schemes have been central to the emergence of *collaborative* governance initiatives. Such interventions can operate within a single organisation or governance arena (e.g. a region or city district), or can take the form of transnational governance arrangements (Bulkeley et al., 2014) or multi-stakeholder initiatives that span a range of organisations and sites. While they take a variety of forms, they are designed to 'generate credibility and authority over production processes in a particular sector' (Ponte, 2014; Schouten et al., 2012) (Bush et al., 2015) or to create consensus amongst actors seeking to govern climate change (Bulkeley, 2012). At their most extensive, 'such as the Roundtable on Sustainable Palm Oil (RSPO) and the Roundtable on Responsible Soy (RTRS), they move beyond a standard setting function to create an epistemic community that establishes the legality, moral justification and consent or justification for their ongoing activity in a sector' (Bush et al., 2015). In the climate governance arena, such established forms of governance initiative can be found, for example, amongst the transnational city networks, carbon disclosure standards, voluntary certification schemes for offsetting and so forth, where initiatives are increasingly woven together in relationships that create a 'transnational regime complex' (IPCC 2014).

A second set of techniques deployed in collaborative forms of governing relate to the creation of green markets through the development of private eco-branding alongside forms of certification within the retail sector, for example supermarkets are seen now to be a 'part of a new regulatory framework governing standards and quality' (Burch and Lawrence, 2005: 12). (Chkanikova and Lehner, 2015). Here the literature points to the new forms of identity and practice being required by (in this case) the retail sector. Addressing sustainability 'requires expertise that goes beyond the core retailing competences of just selling food', which in turn provides the core rationale for the formation of partnerships and networks (Chkanikova and Lehner, 2015: 80). At the same time, it is evident that individual retailers have addressed the potential for eco-branding and the development of green markets in very different ways. The UK food retailer, Waitrose (part of the John Lewis Partnership, which is employee owned) have undertaken £18M worth of investment over ten years in order to develop new standards for milk which 'exceeds those set by the National Dairy Farm Assurance Scheme in a number of areas, e.g. animal welfare, farming practices, wildlife protection and traceability … without passing the price premium to the consumer' (Chkanikova and Lehner, 2015: 79). As this case-study suggests, rather than simply being a method through which information is communicated to customers, such practices of branding, standard setting and certification can be thought of as 'technical devices that assemble … multiple logics and forms of value in ways that actually enable the reconfiguration of markets themselves.' (Pickren, 2014: 32).

To date, there has been much less research on what determines the success or otherwise of such initiatives – an issue partly related to the challenge of evaluating the effectiveness of any one initiative. Within the literature on the governing of sustainability within value chains, recent work by Mylan et al. (2015) provides a clear summary of the three core factors that are thought to shape the nature and extent of interventions in any one arena: 'motivation of supermarkets ("why" implement eco-innovation), which is divided into external pressures and internal considerations, 2) coordination and eco-innovation mechanisms ("how" to stimulate ecoinnovation), and 3) the mediating influence of (pre-existing) supply chain characteristics.' (Mylan et al., 2015: 26; see also Thongplew et al., 2016). Again focusing on the food sector, their analysis finds that the structure of the supply chain in the milk sector (with relatively fewer 'steps' and a more dominant position for the retail sector) was instrumental in creating a pro-active approach to sustainability. They conclude that far from being a straightforward matter of technological development or even the development of niche innovations, fostering sustainability and low carbon transitions required the involvement of large retailers in a

> *'shift in supply chain governance modes and the effective use of innovation coordination mechanisms: economic and information-exchange modes may need to be complemented*

with more subtle modes of governance, such as the collective framing of sustainability issues and the development of shared visions that reduce uncertainty and provide clarity in the orientation of eco-innovation. The cases illustrate that eco-innovation is more likely where governance structures enable more cooperative, collaborative relationships between actors' (Mylan et al., 2015: 27).

Departing from an understanding which suggests that the potential for transitions lies predominantly in the structure of the economic sector (e.g. Li et al., 2015), this approach draws attention to the ways in which the capacity for transitions is also created through the 'subtle governance' of such interventions. Yet it is important also to consider that dynamics of political economy – as discussed in Section 2 – are vital in terms of how such initiatives are cultivated. Chkanikova and Lehner (2015: 82) remind us that the political-economic power of actors across the supply chain is highly uneven and this is critical in shaping how/where sustainability governance takes place, and that when short-term profits are at risk, such initiatives can readily be abandoned. Nonetheless, the power at work in the governing of sustainability and climate change cannot simply be 'read off' from the position of particular actors in an unchanging structure, for 'the power to shape standards that govern commodity networks should not be read simply as a function of class power … it is also the ability to establish a dominant normative paradigm about "quality" that creates legitimacy for standards to operate' (Pickren, 2014: 32, drawing on Ponte and Gibbon 2005).

Advancing our understanding of how/why governance initiatives work requires going beyond the identification of the techniques that underpin particular governance initiatives, to an understanding the *capacity* they produce in order to realise the low carbon transitions. Post-structural political theory can provide insight into these questions. Analysing food value chains, Spence and Rinaldi (2014) use Mitchell Dean's Foucauldian concept of an 'analytics of government' to analyse 'the specific conditions under which a program of corporate engagement in sustainability comes into being and is maintained and transformed within its supply chain, through a set of regimes of practices that aim at embedding the social and environmental impact of business activities into decision- making.' In the realm of climate governance, Bulkeley (2015) examines how governing is *accomplished* through techniques through which the work of authorisation, ordering, calculation and creating publics is undertaken. Drawing across the literature reviewed, four particular capacities seem to be critical to the ways in which the will to govern climate change is realised.

First, as suggested by Bulkeley (2012, 2015), *authorisation* is central to the work of governance initiatives. Several studies point to the ways in which collective legitimacy (often regarded in terms of consensus) is central in explaining the degree to which initiatives take root (Kishna et al., 2016; Niesten et al., 2017). Second, the capacity to produce distinct *qualities* – that sets apart the actors, process or products involved – alongside a desire for such qualities and trust in the claims made about them (Chkanikova and Lehner, 2015; Kirshna et al., 2016; Mylan et al., 2015: 24-25). Third, the capacity of *legibility*, originally defined by Scott (1988), is a critical capacity that serves to define and circumscribe the nature of the problem and how it might be addressed, 'thus management flow charts, maps, organograms, graphs and tables define the objects and subjects of governance' (Spence and Rinaldi 2014: 5; see also Pickren, 2014: 33) and enable intervention to take place. Finally, the capacity of *competency* is formed through technical know-how, scientific knowledge, as well as the material capacities and resources at hand. It is through the iterative work of these capacities that sustainability and climate governance comes to be configured and normalised across value chains and geographical arenas (see Bush et al. 2015: 11 on the importance of governance as normalisation).

5. Advancing the Agenda

While there is increasing interest in how decarbonisation in the heavy-industry sectors might be achieved, our review of the existing state of the research field suggests that there is no one body of work or conceptual approach that is able to develop our understanding of this complex problem. Instead, our review revealed that there are multiple disciplines and research areas that can contribute to developing our knowledge – including those which draw on theories of political economy, governance, innovation and integrated assessment and those which focus on key industry sectors, socio-technical regimes, climate change politics and production/value chains. Working across these diverse fields of research and their different conceptualisations will require flexibility on the one hand and a clear focus on core explanatory variables that cut across different ways of undertaking analysis (e.g. basic social science categories such as structure, agency, power; and core concepts from technical/systems studies such as market, inertia, capital).

Rather than forming a coherent whole, the literature in this area is best viewed as a patchwork, each element contributing to our understanding but still lacking comprehensive coverage. Given that a distinct approach for conceptualising and analysing decarbonisation in these arenas has yet to emerge, it is unsurprising that there are many 'gaps' in the literature. Identifying these areas provides a clear basis for the REINVENT project to develop its specific contribution to advancing the agenda in this arena. Our review identifies five core topics around which new evidence and analysis could significantly advance our understanding of how to foster transitions for decarbonisation:

- Identifying new agents of change
- Developing the conceptualisation of power
- Understanding how materialities matter
- Geographies of deep decarbonisation
- Moving from a sectoral analysis to a systems perspective

First, our review finds that the current literatures of relevance to this field of research focus on comparatively few actors – predominantly nation-states, industrial production firms and end-use consumers. Of particular importance is the lack of engagement with multiple different forms of consumer (e.g. business to business), and different actors across the value chain (from e.g. institutional investors through to consultancy firms and other knowledge providers). Opening up the question of which are the most important agents of change in transitions and understanding their individual and collective effects would significantly enhance our understanding of the field.

Second, and related, questions of power tend to be more implicitly than explicitly discussed in much of the literature concerned with technological innovation and niche-regime dynamics. Underpinning these approaches is an assumed political-economy where it is the relationship between the nation-state and large industry that has the most significant effect in shaping the conditions of possibility for transitions. There is certainly much to support this approach, yet it also has the potential effect of discounting or neglecting other forms of power that are critical in shaping the existing inertia in systems of production and consumption and at the same time missing critical forms of power that are essential for achieving change. Writing in a recent editorial introduction to the analysis of production/value chains, Boström et al. (2015: 5) argue that '*power; power gaps and power asymmetries must be a key focus in understanding sustainability and responsibility in and of supply chains. … [the current] structural and reductionist view of power neglects the role of noneconomic interests and other actors, such as smallholders, local and global NGOs and scientific experts, in shaping these sustainability initiatives.'*

A third area where new research is emerging concerns the materialities of the resources and products that flow through the energy-intensive value chains. The material *qualities* of resources are

central in shaping the extent to which forms of circular economy are regarded as viable. Equally, concerns about the qualities and properties of material are central in shaping the dynamics of technical innovation – whether or not bio-plastics can provide the kinds of quality/value that existing plastics provide, for example, is seen as central to their development. At the same time, we find the literature on governance initiatives indicates that being able to demonstrate particular qualities (and their distinction from existing products/processes) is also critical in the dynamics of change – the roles of monitoring, certification and standardisation are particularly important in qualifying certain kinds of materiality (e.g. low carbon, locally produced). While these elements of the materiality of circular economies, technical/social innovation and governance initiatives are beginning to be explored in the literature, this is another fruitful direction for work in the REINVENT project to contribute towards.

A fourth area of interest concerns the *geographies* of deep decarbonisation. While REINVENT has a specific focus on Europe, the production/value chain perspective requires that we take seriously the global economic production and circulation of resource flows, investment, product and forms of consumption/waste which characterise these sectors. This raises questions about how the spatial organisation of different value chains (within and beyond Europe) shapes their carbon intensity and capacities for transition. The production of paper in Scandinavia has a very different carbon footprint to that in central and southern Europe, due to the availability of different resource flows, forms of power generation, markets and cultural practices. New work on the 'telecoupling' of different regions in global economies (e.g. of soy production in Brazil and cattle farming in Germany) shows how specific regional economic, political and cultural conditions shape the global circulation of value and material (Lenschow et al., 2016: 146). At the same time the capacities for circular economies are also shaped by geographies of the flows of resource and materialities. Analyses of the geographies of waste materials reveal some of the complexity here:

> *'First, the role of intermediary places in acting as a conduit for transactions is apparent. Their infrastructural and institutional capacities enable actors to embed themselves in global networks and sustain the relational coordination of the network. Second, the regulatory regimes of different locations and their articulations are vital to making new commodities from old. Ships and clothing reveal the differential patterns here because of their different materials. The paths of discarded clothes are shaped by the different taxes, values and demands depending on whether they are processed as clothes for re-use or fibres for reweaving in India. Since ships contain hazardous materials, it is the laxer environmental regulation in Bangladesh (and India and Pakistan) that enables their transformation from uneconomic vessels into secondary resources' (Crang et al., 2013: 22).*

A final area in which our review finds that new research is needed to advance the field relates to the current status of much of the literature as predominantly based in a *sectoral* perspective. That is, most of the literature focuses on single sectors (e.g. steel) and particular innovations or initiatives (e.g. energy efficiency technologies). This work has been very important in identifying the *potential* for decarbonisation. It has to date been less successful in identifying the non-technical barriers to change and in identifying what interactive effects of interventions might be and their wider implications (e.g. in terms of social, economic and environmental consequences). In our analysis of the literature, it is apparent that changes in one sector have significant implications for another. For example, the literature suggests quite clearly that the rise of bio-plastics is related to the dynamics within the pulp and paper industry (and vice versa). This suggests that it will be important to examine interventions/innovations at the intersections of the 'sectors' in focus in REINVENT (e.g. meat/milk, paper/plastic, plastic/steel). There are also important upstream/downstream dynamics that are not often captured in the literature. For example, whether significant changes in building design and practice related to pressure to create low or zero carbon structures would create a shift in demand

for steel. This means that in taking our analysis forward it is not possible to examine only how interventions effect any one stage of the value chain, but to also consider their wider implications.

6. Conclusions

Existing research on decarbonisation in the heavy-industry sector is relatively sparse compared to the work that has been undertaken to understand how decarbonisation is taking place in other sectors of the economy, predominantly in relation to energy and transport. At the same time there has been relatively little attention paid to these sectors in the literatures on climate governance and the development of sustainability governance in production/value chains. Many existing studies of the steel, plastic and paper and pulp sectors focus on analysing the potential for technological innovation and developing scenarios for future pathways driven either through processes of technical development or the application of a relatively narrow range of policy instruments (e.g. carbon taxation). This work tends to focus on the production process and on the firm and the state as the key actors involved in transitions. Whilst it provides a valuable basis upon which to build our understanding of how different forms of technical, social and governance innovation might operate in relation to one another, the literature on socio-technical regimes, climate governance and production/value chains suggests that it will be necessary to consider a wider range of actors and the relations between different parts of the value chain in order to fully understand the dynamics of decarbonisation transitions. In the meat and dairy sector research has focused on a wider array of topics, from the development of technical innovation to issues of consumer demand, socio-technical transitions and supply chain governance. The approaches being deployed within the food sector therefore provide a useful entry point for considering the dynamics of decarbonisation in other energy-intensive sectors.

Despite their differences, we find that across the literature there is a broad concern with the political economies within which decarbonisation transitions are situated and configured. Yet to date much of the literature operates with a relatively general understanding of how political economies condition the dynamics of obduracy and innovation. REINVENT has the opportunity to further develop our understanding and analysis of these dynamics. In particular, there is considerable scope for examining the *agents of change* involved in the governing of decarbonisation, both in order to develop a greater understanding of the key actors that have been the focus of analysis to date – the state, the firm, the individual consumer – but also to acknowledge the multiple actors and sites involved in governing decarbonisation. At the same time, the literature review shows that questions of *materiality* are relatively neglected within the literature, and there is considerable scope for developing a greater understanding of the material dimensions of the dynamics of obduracy and innovation through which the potential for decarbonisation is configured. As we take forward the REINVENT project we will explore these opportunities in more depth and test the resulting insights in relation to the evidence gathered through the work programme.

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