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Studying Industrial Decarbonisation: Developing an Interdisciplinary Understanding of the Conditions for Transformation in Energy-Intensive Natural Resource-Based Industry

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Abstract: The ambition to keep global warming well below 2 °C above pre-industrial levels, as recognised in the Paris Agreement, implies a reorientation towards low-carbon societal development and, ultimately, the decarbonisation of human societies and economies. While climate policy has been geared towards achieving set emission reduction targets, the decarbonisation of key socioeconomic sectors such as energy-intensive natural resource-based industries (ENRIs) has not yet been sufficiently addressed, neither politically nor in science. Decarbonising the ENRIs is a complex societal problem that will require structural transformation technologically as well as socially. Understanding the conditions for transformative change therefore necessitates integrated knowledge from multiple perspectives of different research fields. In this paper, we examine the potential of combining three different research fields and critically scrutinize the challenges to integration for understanding the conditions for industrial decarbonisation: energy system analysis, sustainability transition research and policy studies. We argue that these perspectives are complementary—a fundamental condition for fruitful integration—but not easily compatible since they are sometimes based on different ontological assumptions. The research fields are in themselves heterogeneous, which poses additional challenges to an integrated research approach. Drawing on experiences from a Swedish research project (GIST2050) on industrial decarbonisation, we suggest a modest approach to integrated research that could progressively develop from multidisciplinary exchange towards more integrated forms of interdisciplinarity by means of cross-disciplinary dialogue and understanding.

Keywords: decarbonisation; interdisciplinarity; industrial policy; sustainability transformation; climate governance

1. Introduction

In the recent and on-going redirection of climate policy, climate change is being reframed from an emissions problem to an energy system problem or, more broadly speaking, a societal problem. The focus of climate governance is changing from shorter-term mitigation strategies towards longer-term transition pathways for decarbonising societal structures and social practices that generate carbon and greenhouse gas emissions. For long, climate policy efforts were predominantly geared towards achieving set emission reduction targets (e.g., in accordance with the Kyoto Protocol), while strategies to decarbonise key societal functions and systems are yet to be addressed and properly articulated. The ambition to keep global warming well below 2 °C above pre-industrial levels, as recognised by and expressed in the Paris Agreement, implies a reorientation towards low-carbon societal development and, ultimately, the decarbonisation of human societies and economies. Such societal transformations will have to amount to nothing less than structural transformation of every sector of society, including key industries such as energy-intensive natural resource-based industries (ENRIs) accounting for approximately 30% of global greenhouse gas emissions [1]. These industries have previously been largely exempted from progressive climate policies, as that would pose a critical governance challenge for policy makers, i.e., how to decarbonise the ENRIs without compromising the international competitiveness of industries key to national economies.

As the locomotives of industrialisation, the ENRIs have been historically important to the economic development of many countries. But, with deindustrialisation, emergence of new growth markets, neoliberalisation and discredited industrial policy, it became a forgotten set of sectors in the national politics of most advanced economies by the end of the twentieth century [2]. With the dual crises of the economy and climate change in the early twenty first century reminding us of its persistent significance, industrial policy for sustainability transformations is nevertheless once again on the agenda (see, e.g., [3–6]), although not yet fully developed and realised.

This also necessitates a significant catch up in research. Not only have the ENRIs been forgotten in national politics but so too in academia, where they have been largely overlooked in studies of sustainability transitions and decarbonisation. For example, sustainability transition research (STR) has become a dominant influence setting the agenda for research on sustainability and low-carbon energy transitions over the last decade, but empirical studies have so far focused on the energy, transport, buildings, water and waste management sectors, while the ENRIs have been less studied. Not only have they been overlooked empirically but also conceptually—the ENRIs have a number of characteristics that pose conceptual challenges to STR, an issue we return to in this article. Thus, given the complexity of decarbonisation and the characteristics of the industry, we need to engage with a broader set of perspectives to better understand the conditions for structural transformation and decarbonisation of the ENRIs.

This need for integrated research beyond disciplinary boundaries is not unique to the ENRIs, but has become increasingly obvious in science in general, and in research related to sustainability in particular. Although integrated research holds great promises, there is as of yet a lack of interdisciplinarity in energy research [7]. The necessity to integrate perspectives does not necessarily make it an easy task though. On the contrary, it has been argued that with regards to interdisciplinarity, "hope tends to triumph over experience" [8] (p. 595), and it can be used "more as virtue signalling than for genuine application" [9] (p. 1). For research projects intent on conducting interdisciplinary studies, it is therefore important to reflect upon the possibilities and barriers of doing so successfully.

The aim of this paper is to examine the potential of combining different research fields for understanding the conditions for industrial decarbonisation, including to critically scrutinize the challenges of such integration. We do this by drawing on experiences from the research programme Green Industrial Sustainability Transitions (GIST), which had the overarching research objective to study the conditions for decarbonisation and structural change in the Swedish ENRIs and to explore possible pathways and strategies for governing such industrial transformations. By conceptualising stability and change of the sociotechnical system differently and by endowing various factors causal efficacy, different perspectives focus on different aspects and infer different governance approaches. We explore perspectives and approaches within three research fields employed in the GIST project, which are relevant for understanding the conditions for governing energy system transformations in general and industrial decarbonisation in particular: energy system analysis, sustainability transition research and policy studies. These research fields are in themselves heterogeneous, with different approaches and assumptions, which poses additional challenges to an integrated research approach.

The Green Industrial Sustainability Transitions (GIST) project brought together 12 researchers from the Department of Technology and Society, Centre for Innovation, Research and Competence in the Learning Economy (CIRCLE), Economics, and Political Science at Lund University. It ran between 2015 and 2018, and was funded by the Swedish Energy Agency. The project was organized into two modules:

(1) theories and methods for transition studies and (2) the carbon-intensive basic material industry. Researchers from the different fields participated in both modules and an important mechanism for interdisciplinary dialogue was the recurring project meetings in which all project members participated. Results from the project have been presented in a series of publications representing the different research fields reviewed in Section 4 as well as in an integrated policy report on the preconditions for industrial decarbonisation in Sweden as discussed in Section 5.

This paper is structured in the following way. First, we introduce and provide the reader with a basic understanding of the main characteristics of ENRIs before we go on to present key insights from the literature on interdisciplinarity. Informed by this, we then summarize and compare the main thematic contributions of the selected research fields, their ontology of change and approaches to governance. From this follows a discussion about the possibilities and challenges of integrated research, as well as the potentials for and difficulties involved in developing an interdisciplinary understanding of the conditions for governing structural transformations in ENRIs. While our analysis is illustrated by experiences from the GIST project, we draw conclusions of general interest about both the challenges for an integrated research approach and the need for a broader understanding of the conditions for industrial transformations.

2. The Energy-Intensive Natural Resource-Based Industry (ENRI)

The need for integrated research does not arise in abstract but from the complexity of concrete phenomena and problems. Integration of knowledge from different research fields should therefore be considered in relation to the characteristics, or nature, of the research object as well as the specific research problem of the study/project. In this section, we examine the characteristics of the ENRIs in Sweden.

The ENRIs are, as the name indicates, energy-intensive industries involved in extraction of natural resources (extractive industry) and processing of these into basic materials (process industry). They are sometimes also called basic industries, or basic materials industries, and include:

- the mining industry,
- the iron and steel industry,
- the aluminium industry,
- the paper and pulp industry,
- the chemicals and petrochemicals industry,
- the cement industry and, sometimes,
- the glass industry.

In Sweden, ENRIs were the main locomotive of industrialisation from the mid-nineteenth century onwards and retained a central role in the economic development of the country for the greater part of the twentieth century. Since the 1980s, the ENRI share of economic activity, export revenues and employment has decreased with the advent of the knowledge economy, deindustrialisation and changing industry composition [2]. But with regards to greenhouse gas emissions and energy use, the importance of ENRIs has increased—nowadays accounting for approximately 30% of Sweden's total energy use and carbon dioxide emissions [2]. The ambition of the Swedish government is to become a leader of ENRI decarbonisation, while avoiding carbon leakage and promoting reindustrialisation. In response, industry sectors have recently launched new roadmaps for decarbonisation and are engaged in public–private collaborations on specific projects such as the decarbonisation of steel making through hydrogen technology.

From a societal point of view, deep decarbonisation of the ENRIs is an important collective interest, as the sector accounts for a substantial share of global carbon emissions. However, for individual firms, decarbonisation is a challenging objective as it is associated with few direct co-benefits for producers and end users. Decarbonised production processes generally produce the same products but at a higher cost. Deep decarbonisation is therefore unlikely to occur spontaneously and will require strong regulatory interventions and policy support to break with business as usual (see further, e.g., [3–5]).

At the same time as ENRI firms often compete on highly globalised markets, they are also of strategic importance for the national balance of trade and for employment. Therefore, to maintain global economic competitiveness, and avoid so-called carbon leakage, the ENRIs have so far been sheltered from regulatory pressure to lower greenhouse gas emissions that could increase direct and indirect costs. In Europe, ENRI firms have, for example, mainly received free allocation of emission permits in the EU Emissions Trading System (EU ETS) and have to a large extent been exempted from electricity and energy taxes [10]. For further elaborations on the effects of EU ETS, and specifically of free allocation of emission permits, on the economic and financial performance of firms, see [11,12]. Not only is regulatory pressure to lower greenhouse gas emissions low, but so is consumer pressure, since the ENRIs supply manufacturing sectors with basic materials, distant from end consumers.

Incentives and pressure to radically decarbonise have thus been weak so far. Rather, "the regulations that are in place focus on incremental innovations that also have economic benefits, examples are energy efficiency improvements, fuel shifts and minor process improvements" [13] (p. 1309). This focus on incremental process innovation to enhance productivity leads to lock-in and inhibits the more radical innovations necessary for deep decarbonisation. Furthermore, investments in R&D is typically low in ENRI firms, and "although government supports deep decarbonization throughout the R&D and pilot stage, support for upscaling through a stronger demand-pull and effective regulations are lacking" [13] (p. 1309).

The technical systems of the ENRIs are generally large technical systems, which are capital intensive and characterised by long-term investment cycles. They are sensitive to failures in the production process, to earn back the high investment costs, which has led to high risk perception of innovations [13]. In Pavitt's [14] taxonomy of different categories of industrial firms, the ENRIs are often identified as scale intensive. Scale-intensive firms typically produce bulk materials, are generally large cost-cutting firms competing by economies of scale and geared towards incremental in-house process innovation. This ideal type corresponds well with many ENRI firms but since most operate in complex global systems, the general trajectories and characteristics identified by Pavitt cannot be assumed automatically. For instance, to maintain profitability on global markets, production in certain sectors in Sweden (such as the steel industry) has moved away from bulk production, towards more advanced product categories and specialised applications. The dynamics and characteristics of firms in these specialised material markets can be different from firms in basic material markets [13].

This characterisation of ENRIs highlights a number of challenges with regard to deep decarbonisation. Privately owned large capital-intensive technical systems competing by economies of scale create powerful vested interests, lock-in, and high barriers to entry for new actors. This, in combination with few co-benefits for users and producers, and exposure to international competition, has so far impeded the structural transformation necessary. Research on this complex problem needs to examine the mechanisms currently preserving business as usual, and what mechanisms can transform it. To do so involves analysis of structural constraints and possibilities, of power relations and agency, along multiple aspects and scales, including, e.g., technological innovation systems, energy systems, policy regimes of the regional and national economy, and the global economy. Since none of the research fields cover this complexity in its entirety, integration of knowledge is necessary.

3. The Necessity and Possibility of Interdisciplinarity

With complex societal problems comes the need to move beyond disciplinary boundaries for a more complete understanding of the problem from different perspectives. Rittel and Webber [15] used the term "wicked problems" to describe societal problems that are characterized by "interdependencies, uncertainties, circularities and conflicting stakeholders" [16] (p. 1159) making them particularly difficult to handle. Climate change has been described as a "super wicked problem" since there is added complexity with the time urgency, global implications, the profound effects on all levels of society and the complex interactions between human and natural systems [16,17].

Decarbonising the ENRIs is a complex problem involving a multitude of aspects and actions on multiple scales and under strict time constraints. The question "How can the ENRIs be decarbonised?" includes a myriad of sub-questions such as: What are the technical options for decarbonisation? How will decarbonisation affect the energy system as a whole? How can innovation and technology development be understood and supported? What are the social dynamics and impacts of a restructured industry? What are the political and policy challenges involved? Since no single study or scientific approach can provide an answer to all aspects of the question, there is need for interdisciplinary research, either through dialogue or integration between disciplines.

Schmidt [18] refers to problem-oriented interdisciplinarity as one specific type of interdisciplinary research where a certain societal problem is the starting point and motivation of interdisciplinary cooperation. Schmidt [18] argues that the framing of the problem is an essential part of a problem-oriented approach asking critical questions about "*who* is considering *what* as a problem and *why*?" (p. 258). Problem framing can thus not be thought of as value free but includes normative elements and needs to be done reflexively. The societal nature of problem-oriented interdisciplinary research makes interaction with societal actors an important aspect, either directly into the research endeavour (making it transdisciplinary research) or indirectly by the researchers taking societal concerns into account. Schmidt takes a fairly pragmatic approach when it comes to ontological and epistemological positions and does not say much about how researchers from different disciplines should cooperate and the nature of scientific integration within problem-oriented research.

An account that attends to the ontological and epistemological considerations of interdisciplinarity more in depth is provided by Bhaskar et al. [19]. Based on critical realism, Bhaskar et al. argue that interdisciplinary research is necessary to study complex societal phenomena since they are determined by a multiplicity of determinants, while individual disciplines study the causal mechanisms emergent from specific levels of reality and orders of scale. Reductionist disciplinary research is thus necessary to examine the specific determinants emergent from each level but must be integrated with knowledge from different fields in order to analyse complex phenomena. However, for truly interdisciplinary synthesis, "purely additive pooling of the results of the knowledge of the distinct mechanisms" [19] (p. 4) is not enough. Instead, there is a need for theoretical integration between different fields, which nevertheless can be difficult to achieve. Different theories do not only come with different thematic contributions but often also with different fundamental ontological and epistemological assumptions, principles and orientations, making them more or less incompatible.

The problem of incompatibility of differing theories has been argued most famously by Kuhn as the incommensurability thesis. Kuhn's concept of incommensurability of scientific paradigms has been used to justify the idea that cross-disciplinary understanding across paradigms is essentially impossible. However, as one of the most widely discussed ideas in the philosophy of science, it has not gone unchallenged. The discussion will not be rehearsed here but it has for example been pointed out that the relation between two theories is seldom one of strict incommensurability or uniformity [20]. By exaggerating the internal unity of theories and underestimating the unresolved tensions within theories, it might appear so, but the reality is often in shades of divergence and mutuality [20]. Furthermore, "for two sets of ideas to be in contradiction they must also have certain terms in common, over which they can contradict one another" [21] (p. 73). Cross-disciplinary understanding is, in other words, difficult but not impossible.

Preferably, we would have the same ontological orientation across all theories in order to speak the same meta-theoretical language and to integrate theories [22,23]. But, where that is not the case, we at the very least need an understanding of the differences between different disciplines, approaches and perspectives for 'cross-disciplinary understanding', i.e., "the potential to empathize with and understand and employ the concepts of disciplines and fields other than one's own" [19] (p. 11).

In Section 5, after reviewing our three research fields, we return to the question of interdisciplinary integration, the barriers against it, and the possibility of integrating by exploring theoretical tensions.

Before we move on, a note on terminology is necessary. As the demand for, and occurrence of, research beyond disciplinary boundaries has increased, so has the terminological variation and confusion. For the sake of clarity, we will stick with Stock and Burton's terminology [24]. Interdisciplinary is often used as the collective noun for all categories of integrated research, but since interdisciplinarity is also used to define a particular type of integration, we will follow Stock and Burton and use the term integrated research as the collective noun. The three most common terms—multidisciplinary, interdisciplinary and transdisciplinary—are defined as "a hierarchy in terms of the extent of integration and holism invoked by the term" [24] (p. 1094). Multidisciplinarity is characterised by disciplinary research that is coordinated but not necessarily integrated. Its advantage is that "while the research approaches are disciplinary, the different perspectives on the issue can be gathered into one report for assessment" [24] (p. 1095). One step up with regards to "the level of integration and cooperation" [24] (p. 1096), interdisciplinarity involves iterative research process between perspectives to jointly frame problems, explore and resolve contradictions, and analyse data. Finally, transdisciplinarity—the highest form of integration—"combines interdisciplinary with participatory approaches" for "a holistic approach to problem solving involving stakeholders and scientists in a joint project" [24] (p. 1098).

In the remainder of this article, we will review and discuss three research fields, with different disciplinary backgrounds, that have been represented and utilised in a research programme on the decarbonisation of the ENRIs in Sweden (the GIST project). The research fields reviewed are energy systems analysis, sustainability transition research and policy studies. They are all interdisciplinary in themselves and will therefore be called research fields rather than disciplines. Within each field, there are different approaches, theories and perspectives that draw on a variety of paradigms. The three research fields of this study—and the approaches, theories and perspectives within these fields—are not the only ones relevant to understanding the conditions for transformations in the ENRIs but each of them contributes with vital knowledge. The aim of the review, and of this paper, is not to give an exhaustive answer to the research problem, but to explore both the advantages of an integrated research approach and its challenges and difficulties.

Thus, the results of this paper consist of the experiences from dealing with the challenges of interdisciplinary work in an actual research project, challenges that are of general interest to other scholars conducting interdisciplinary research. Our project represented a typical research project where scholars from different disciplinary backgrounds come together to conduct multidisciplinary work on a policy relevant topic. Our ambition is to present the research process, including the three research fields, in a transparent way, and reflect on the challenges encountered.

4. Three Approaches to the Study of Industrial Decarbonisation

First, the research field will be briefly introduced, followed by a discussion of its main thematic contribution to the research problem. Different approaches are interested in different problems and thus ask different questions. Each approach or discipline can make its contribution to the overall research question, and together they can provide a broader picture of the problem area. Second, the ontological orientation of the approach will be discussed. This is important since different theoretical perspectives make different ontological assumptions about the nature of the world, and thus ontologically privilege some causal entities and mechanisms over others. This implies that theories of different ontological orientation have different ideas about, for example, what change is, what the drivers of change are, and the nature of structure and agency. Focus on some aspects, research problems and causal relationships necessarily means that others are omitted. A discussion on ontological orientation is also necessary in order to understand to what degree a meaningful dialogue can be developed between approaches. Third, theories are used to inform analysis of, for example, transition mechanisms and actualisation, which in turn might inform policy recommendations and actor strategies more generally.

It is therefore important to consider the governance implications of different approaches—what they focus on and leave out, and how they aim to support policy making.

4.1. Energy System Analysis

4.1.1. Main Thematic Contribution

Energy system analysis is a heterogeneous and loosely defined research field that is devoted to studying the interactions of different parts of the energy system and how it might evolve. It is often characterised by problem-oriented studies that are policy-oriented as well as multidisciplinary. Energy system analysis can include many methodological approaches such as quantitative modelling, scenario analysis, technology assessment and sociotechnical studies.

In relation to sustainability transitions, a main contribution of energy system analysis is to provide a technical understanding of what is possible and technically required to achieve a certain predefined objective (e.g., a 100% renewable or a zero-carbon energy system) and to relate this to the sociotechnical context and policy needs. Technology assessment and scenario studies are two particular strands of energy system analysis that will be highlighted here. Technology assessment deals with the study and evaluation of new technologies regarding both their potentials and risks, and their implications in existing sociotechnical systems, with the aim of providing input to decision makers about the effects of a technology [25–27]. Scenario studies aim at studying the future development of, e.g., the energy system or a particular technology within that system. Scenarios can be of different kinds and can be designed to be either predictive, explorative or normative [28], of which the latter is often associated with the method of backcasting [29].

For the energy-intensive basic materials industry Max Åhman and colleagues have made several studies in the GIST project of the technical options and potentials for industrial decarbonisation in Sweden [30], the EU [10] and globally [31]. In these studies, an overview is made of the different technological options for long-term industrial decarbonisation (such as, e.g., industrial electrification, biomass substitution, carbon capture and storage and utilisation) and these are analysed in terms of their potentials and possible obstacles. The findings are then related to the economic and political context and the need for policy development, although no deeper analysis is made of policy challenges or how policy change can be brought about. Another type of study is conducted by Lechtenböhmenr et al. [32], where they, with the use of scenario analysis, explore the consequences of choosing one particular technological path for decarbonisation of the energy-intensive basic materials industry in the EU, namely electrification combined with 100% renewables. They find that it is technically possible to do this but that it will require a very large increase in renewable electricity, that electricity prices will increase and that there will be profound changes in the interlinkages between the industrial and energy systems.

4.1.2. Ontological Orientation

Energy system studies developed as an academic discipline in the 1970s in response to the energy and resource crisis. It developed against the backdrop of a positivist tradition within engineering and natural science, with the ambition of aiding decision making, but without ambition or theory to explain wider societal consequences and dynamics. The main part of energy system analysis is still carried out in this vein, such as energy system modelling, traditional technology assessment and scenario analysis. These approaches are problem oriented and aimed at aiding policy making, but there has been limited interest in theory development or reflecting on a coherent ontological position.

However, within energy system analysis, there are also more sociological and sociotechnical approaches that have different and more clearly defined ontologies. Examples are science and technology studies (STS) and constructive technology assessment (CTA) [25], which are critical of the positivist position, and have developed theories of how technologies are socially constructed, meaning that their value and use are continuously interpreted and negotiated in society.

There are thus several different types and paradigms of energy system analysis, but at its most basic, energy systems analysis is a systems theory. Broadly defined, systems are "sets of elements standing in interaction" [33] (p. 38), or more precisely, a system is "an organized whole in which parts are related together, which generates emergent properties and has some purpose" [34] (p. 58). The objective is often not to "understand what things are made of, but rather how they are compounded and work together in integrated wholes" [34] (p. v), i.e., identify the emergent properties and dynamics of different systems. Although energy systems analysis rests on these implied assumptions, a great degree of autonomy is awarded to the individual scientist in defining, boundaries, elements, and other parameters, creating a great variety of approaches.

4.1.3. Governance Implications

As outlined above, much of energy system analysis has a deliberate ambition to be policy relevant and to aid policy makers in decisions on the development of the energy system and future technologies. Technology assessment can provide information on existing and upcoming technological options, their potentials, advantages and possible side effects. It can also shed light on barriers and incentives for technological change (mainly technical and economic). Scenario analysis is used to explore future (sustainable) energy systems and contribute to envisioning and co-ordination of policy efforts and governance initiatives.

4.2. Sustainability Transition Research

4.2.1. Main Thematic Contribution

Sustainability transition research (STR) is devoted to conceptualising, explaining and governing sociotechnical transitions towards sustainability. Such transitions are understood to go beyond incremental technological improvements to rather entail radical changes in the way in which societal functions are fulfilled at the level of sociotechnical systems [35], i.e., they also include "changes in user practices and institutional (e.g., regulatory and cultural) structures" [36] (p. 956). Transitions are mostly situated at the meso level, between the macro level (e.g., the capitalist techno-economic paradigm) and micro level (e.g., individual technological discontinuities). Within this field, four broad frameworks have gained prominence: the multilevel perspective (MLP), technological innovation systems (TIS), transition management (TM), and strategic niche management (SNM). This section focuses on the MLP and TIS, whereas the more prescriptive frameworks TM and SNM are confined to the section on governance.

Research on TIS is concerned with the systemic context of technological innovations and the impact it has on development, diffusion and utilisation of particular innovations [37]. The most prominent current within TIS has been to evaluate this systemic context in terms of key functions vital to the performance of the innovation system [38–40]. Recent criticism of neglect of wider structural contexts has, however, led to a return "to the relationship between TISs and contextual systems" [41] (p. 52), highlighting among other things geographical relations (see, e.g., [42]).

Whereas energy system studies, and to some extent TIS, lack a theory and understanding of change dynamics, the very core of the MLP is to conceptualise "overall dynamic patterns in sociotechnical transitions" [43] (p. 26). These dynamics are conceptualized as a co-evolutionary interplay between three different levels of structuration: niches, regimes and landscape developments. Niches are small and unstable, regimes are dominating and more stable, while the landscape level encompasses broader background structures beyond direct influence of particular actors (i.e., exogenous developments). On the basis of identified "recurrent patterns" [43] (p. 38), the MLP "specify general forms of transitions" [44] (p. 99), or so called 'transition pathways'. The MLP has been further developed by Fuenfschilling and Truffer [45], who introduced an institutional logics approach for a more fine-grained appreciation of transition trajectories.

STR can thus inform current and future transformation of ENRIs with insights about the dynamics of previous transformations and of the systemic context of innovation. In the GIST project, Wesseling et al. [13] have examined how the characteristics of ENRIs might influence the transition of the sector towards sustainability and identified gaps in the STR literature with regards to ENRIs. Against the previous neglect in TIS studies of incumbent mature industries like ENRIs, Wesseling and Van der Vooren [46] examine how the systemic lock-in that characterizes mature innovation systems hampers transformation towards sustainable production of concrete, and Hansen and Coenen [47] analyse resource mobilisation by incumbents for biorefineries. Further analysis of the systemic context of biorefinary innovation is contributed by Bauer et al. [48] who examine "aspects of collaboration in the bioeconomy by looking at the development of innovation networks for biorefinery technologies" (p. 1). Bauer and Fuenfschilling [49] have studied the interactions between the local level and global regimes in the development of sustainability initiatives in the chemical industry. Svensson [50] has studied how the material properties of natural resources conditions transitions and has, in this process, criticised previous theories, particularly the MLP, for lacking a proper account of material conditions [51].

4.2.2. Ontological Orientation

The frameworks of STR draw on different disciplines but are all rooted in evolutionary economics [52] and the history and sociology of technology [53] for their conception of the regime—the most central concept for their understanding of stability, and to some extent change. Therefore, they all acknowledge phenomena such as "path dependency, lock-in, interdependence, non-linearity and coupled dynamics" [40] (p. 597), but they also differ in important ways.

In TIS, the structural components making up the system are actors, networks and institutions. But, with the functional turn, it is functions that are foundational, as functions mediate between structural components and the effects on the innovation process. Interaction between different functions might create non-linear dynamics of the innovation process. If linkages between functions are circular, processes of 'cumulative causation' set in, that create, what Myrdal [54] called, virtuous cycles [39,55,56]. These ideas of reinforcing linkages and non-linear dynamics are also a legacy of Dahmén's [57] ideas of complementarity and development blocks. In response to the functional turn, recent work (not the least on the spatial aspects of innovation systems) has reasserted the importance of structural contexts [41].

The MLP has its theoretical background in a crossover between evolutionary economics, constructivist theories such as social construction of technology (SCOT) and actor–network theory (ANT) from science and technology studies (STSs), structuration theory and neo-institutional theory [44]. The MLP has adopted the assumption, shared by these ontologies, of "creative and heterogeneous actors" who are embedded in regimes that guide behaviour [58]. The regime here "refers to the semi-coherent set of rules that orient and coordinate the activities of the social groups that reproduce the various elements of sociotechnical systems" [43] (p. 27). The regime concept, which is central in accounting for path-dependence, has nevertheless been criticised as being too internally coherent and lacking internal contradictions in empirical applications. The concept has therefore been further operationalized by Fuenfschilling and Truffer [45] who, inspired by institutional theory, brought in tension and disequilibrium as endogenous qualities of the regime and conceptualised the different levels of structuration (niche, regime, landscape) as degrees of institutionalisation. Drawing on structuration theory, structure and agency are considered mutually constituted and instantiated in routinized practise as sociocognitive rules [44]. The MLP is thus a process ontology that rejects focus on entities to rather "explain outcomes as the results of temporal sequences of events and the timing and conjunctures of event-chains" [44] (p. 93).

4.2.3. Governance Implications

Governance of transitions is central to STR, and can generally be said to focus on processual strategic guidance rather than traditional policy instruments, such as, e.g., taxes, subsidies and regulations (which is often the policy advice of energy system analysis) [35,59]. Against top–down governance by traditional instruments, emphasis is put on reflexive and evolutionary management, involving learning, envisioning and networking involving a plurality of actors in systems conceptualised as complex, uncertain and adaptive.

Strategic Niche Management (SNM) and Transition Management (TM) in particular have prescriptive interventionist agendas. SNM, which is closely related to the MLP, is about reflexive creation and management of protected spaces for development of new promising technologies by means of experimentation [60]. Creating space for niches and focus on frontrunners is also key in TM, which is a more encompassing policy framework. Based on complex system theory, transition management is understood as recursive cycles of problem structuring, envisioning, development of coalitions and agendas, agenda implementation, monitoring, evaluation and learning [61].

Often TIS analyses are also intended to inform policy making. Assessing functional weaknesses (rather than structural deficiencies) of innovation systems, TIS researchers identify 'blocking mechanisms' and 'system failures' (rather than simply market failures), to suggest policy interventions for specific innovation systems [38].

4.3. Policy Studies

4.3.1. Main Thematic Contribution

Policy studies represent a broad field of theories and disciplines engaged with the study of policy processes and instruments. A distinction could be made between policy studies aimed at understanding and developing theories of the policy process (see, e.g., [62]) and policy analysis approaches aimed at providing policy advice [63]. Studies in the latter category are engaged in analysing feasible policy options, effective policy instruments and problems of policy implementation, while policy theory studies strive to better understand decision making processes, conditions influencing policy processes and factors explaining policy change.

Within the broader field of policy studies, some studies have engaged with questions about policy change in relation to decarbonisation. Drawing on the concept of path dependency and scenarios for policy change developed by Cashore and Howlett [64], Levin et al. [17] explored plausible policy logics for change and path creation in response to climate change. They emphasize the often neglected "progressive incremental" type of policy change, representing situations in which a series of incremental steps over time accumulate and lead to changes of an increasingly progressive nature. To account for this, Levin et al. suggested an applied forward reasoning approach to better understand how progressively incremental processes of change could be nurtured to facilitate learning, durable impact on specific policy problems and the creation of policy pathways towards decarbonisation. Bernstein and Hoffmann [65] emphasize how such decarbonisation pathways are inherently political and generated by social processes and interventions undertaken by actors at different sites of governance. Other authors have emphasised the role of the state and have explored how green states can be engaged in the governance of low-carbon transitions [66,67].

Relating to the GIST project and ENRIs, Bataille et al. [68] conducted a study where they review the potential of various policy options that can drive innovation and investment in near commercial low-carbon technologies for different industry sectors. Åhman, Skjaerseth and Eikeland [69] carried out a policy assessment of the EU NER 300 policy aimed at funding innovative low-carbon demonstration projects in the energy and industry sectors. Hildingsson and Khan [70] made a broad analysis of climate policies in Sweden subject to their capacity to support innovation and create policy pathways towards low-carbon transitions. Relating to theories developed by Levin et al. [17], Hildingsson and Khan [70] found support for a gradually more progressive approach to policy change in the case of the Swedish energy transition. Taking a wider governance perspective, and with Sweden as an example, Hildingsson, Kronsell and Khan [71] analysed the role of the state in governing the decarbonisation of ENRIs, while Kronsell, Khan and Hildingsson [72] studied actor relations in climate policy making. They find that the tension between the state's economic imperative and ecological concerns in greening industry are shown to persist. However, as the energy-intensive industry's previously privileged position in the economy is weakening, industry has opened up to decarbonisation strategies.

4.3.2. Ontological Orientation

Policy studies are heterogeneous and draw on multiple theories with different ontological and epistemological orientation ranging from rationalist to constructivist and post-positivist approaches. However, most policy theories share, in common with institutional theory, an institutional understanding of policy change as context-dependent and bounded, in which policy change was traditionally understood as discontinuous and drastic and occurring at critical junctures in response to major political shifts and events. Policy analysis, on the other hand, is often problem oriented and shares a rationalist ontological orientation similar to what we find in energy system analysis, including a more prescriptive ambition to provide policy makers with evidence-based advice.

A key concept in institutional theory is path dependency, central to political scientists (e.g., [73,74], sociologists (e.g., [45]) and institutional economists (e.g., [75]). The concept is also of central relevance in studies of transformational change. Path dependencies occur due to inertia and change resistance generated by self-reproducing mechanisms such as lock-in (e.g., sunk costs), self-reinforcement (e.g., vested interests), increasing returns (e.g., economies of scale) and policy feedback mechanisms (see, e.g., Pierson [76] building on North [75]). Such mechanisms have primarily been taken into account to understand stability and how ideas, norms, rules and patterns of behaviour get socialised, institutionalised and sedimented in policy practices and organisational structures. The change-resistant nature is inherent to the very definition of the institutional concept, accounting for institutions as the "*relatively enduring* features of political and social life ... that structure behaviour and that cannot be changed easily" [77] (p. 4). That includes both formal (rules and regulations, policies, bureaucracies and organisations) and informal institutions (norms, ideas, cognitions, procedures) that set the 'rules of the game' [75]. Once established, an institutional logic is hard to reverse, which explains the typically incremental nature of politics and the gradual development of public policies.

However, more recent studies provide a more dynamic perspective on policy change and have shown how seemingly stable institutions do change, not only due to exogenous pressures and events, but through endogenous mechanisms such as displacement, layering, drift and conversion of established arrangements [74,77,78]. Similar kinds of mechanisms could, as argued by Levin et al. [17], be utilized and enacted by progressive actors to challenge established courses of action and to enter new policy pathways. Thus, the logics and mechanisms generating path dependency should be understood as both stabilising and destabilising features that could either constrain or enable processes of change.

Once accumulated, such processes might generate windows of opportunity [79] that open up for policy reforms, new ideas and alternative courses of action previously seen as inappropriate or infeasible. As argued by Mahoney and Thelen [77], institutional change might not even have to entail policy or organisational reforms, but could be an outcome of distributional conflicts and political debates over prevailing institutions: "institutional change often occurs precisely when problems of rule interpretation and enforcement open up space for actors to implement existing rules in new ways" (p. 4). Such ambiguity is what provides room for agency and gets various actors to challenge, reconceptualise and adjust institutional arrangements to shift the balance of power between different interests.

4.3.3. Governance Implications

Policy studies engage directly with the issue of governance, both in the exploration and theorisation of the policy process, and in policy analysis by providing policy advice. While policy analysis contributes with ex ante assessments of different policy options (e.g., [68]) as well as evaluations of ongoing or completed policy instruments (e.g., [69]), policy theory provides an understanding of the policy challenges involved and the conditions for policy making and governance of relevance for industrial decarbonisation. This could include agency-oriented and structural (institutional, discursive, normative) explanations as well as understanding mechanisms that might trigger change and create room for policy change. Other studies focus on the role of the state in relation to other actors and explore the governance conditions for employing decarbonisation strategies (e.g., [71]).

5. Discussion: The Possibilities and Limitations of an Integrated Research Approach

Each of the three fields reviewed in Section 4 offers important knowledge (summarised in Table 1), but none of them can provide comprehensive explanations. Energy systems analysis examines the technical potentials and challenges for decarbonisation and relates this to policy solutions needed today. Transition studies analyse the mechanisms by which technological innovation occurs, and the role of different actors and policies in the system. Policy studies explore the role of governance and institutions and inform about the challenges and conditions for policy change in the transition.

Table 1. Three approaches to the study of industrial decarbonisation.

	Main Thematic Contribution	Ontological Orientation	Governance Implications
Energy System Analysis	Quantitative modelling, scenario analysis, technology assessment and sociotechnical studies.	Systems theory; problem oriented; ranging from positivist to constructivist approaches.	Aid decision and policy makers by anticipating potential impacts. Overcoming barriers to change.
Sustainability Transition Research	TIS: Assessment of conditions for implementation of innovations. MLP: Processes and pathways of sociotechnical transitions.	Evolutionary theory; structuration theory; practice theory; functionalism.	Reflexive and evolutionary management, involving learning, envisioning and networking and a plurality of actors. Assess weaknesses of innovations systems.
Policy Studies	Policy theory: Study of the policy process and factors explaining policy change. Policy analysis: Evaluation of policies to provide policy support.	Heterogenous; ranging from rationalist to constructivist and post-positivist approaches. Institutional theory.	Policy theory: mechanisms of change and institutionalisation; understanding policy processes, actor relations and institutional inertia. Policy analysis: Ex ante and ex post evaluations of policy options.

In this discussion, we make three claims about the possibilities and limitations of an integrated approach to studying sustainability transitions in general, and decarbonisation of the energy-intensive industry, in particular. First, we propose that integrated research beyond disciplinary boundaries is crucial for a broader understanding of the problem at hand in order to make informed policy decisions. This will provide policy makers, and other societal actors, with knowledge on policy conclusions from different perspectives in a coherent setting. It also means that researchers from different research fields need to work in close cooperation and engage in dialogue on their research findings, based on a mutual understanding of each other's perspectives. Second, we argue that there are some inherent differences between the perspectives reviewed in this paper (and likely also between perspectives from other traditions) which makes it difficult, not even fruitful, or sometimes impossible to merge them into one common framework or interdisciplinary model. These differences are both of an ontological nature and also concern the methods used and theoretical underpinnings. The perspectives can, thus, be said to be complementary but not easily compatible. Third, we suggest that a feasible way forward in practical research is to work with integration as a developmental process.

In order to illustrate the merits of an integrated research approach, we draw on examples from the GIST project. The project brought together researchers from the three research fields around a common core problem—to understand the conditions for decarbonisation of ENRIs in Sweden—but without a joint theoretical framework. The necessity of an integrated research approach to the project was a consequence of it being problem oriented, and the specific perspectives were justified by their relevance with regards to the problem. The ambition was not to create a model or meta-theoretical framework that would integrate all perspectives. It was rather to integrate complementary perspectives where it was helpful for the specific problem of industrial decarbonisation. It was also recognised that some perspectives were not easily compatible, and that such attempts would have stifled initial progress in the project and risked alienate some members of the project from the ambition to cooperate. As we elaborate in the following sections, throughout the project we gradually explored how the perspectives complement each other and what theoretical tensions make them not easily compatible. This was done in a processual manner through among other things common reports and workshops, which in the end broadened the problem frame.

In the following sections, we examine theoretical limitations and tensions within and between different perspectives, and how they might be complementary, inspired by the method of immanent critique [80] and Lakatos idea of progressive and degenerative research programmes [81]. For meaningful exchange across disciplinary boundaries, we consider complementary among the perspectives a condition. This entails that the different perspectives focus on different aspects of the same problem (differing main thematic contribution) and combine in such a way as to resolve some of the theoretical limitations and tensions of the other perspectives.

5.1. Complementarity

First, to decarbonise the ENRIs requires new technologies but the knowledge on technological options was not well developed. Thus, there was a need in the project for basic technology assessment studies, exploring the technological options and analysing them in terms of feasibility, energy system implications, costs and policy options (see, e.g., [31]). The techno-economic evaluation of energy system studies can, however, only say so much about the problem of decarbonising industry. It, for example, lacked a dynamic theory of change processes, often oversimplifying social aspects of the implementation of new technologies, and disregarding politics and power.

Second, the raison d'être of STR is that "beyond incremental environmental innovations, we need major, system-wide changes that are likely to involve breakthrough technologies and possibly fundamental changes in social aims, institutions, industrial structure and demand" [82] (p. 7). To understand the conditions for decarbonisation of the ENRIs, we had to study the dynamics of such radical change. Transition studies have hitherto not engaged very much with energy-intensive industries and there was thus a need to develop these theories to a new empirical setting. Considering for example the capital-intensity, large-scale, long-term investment cycles, and focus on incremental process innovation, that create strong lock-in, we are unlikely to expect wide-spread niche-cumulation of radical innovation in this industry. We therefore need a better understanding of regime transformation and a broader set of conceptualisations of the dynamics of industrial transformation. This has for example led to increased attention to the importance of material properties and relations [51], the role of incumbent industries [46,47,71] and the interaction between global and local levels [49].

TIS complements energy system studies by assessing the conditions for successful implementation of technologies in terms of how well the actor constellations, networks and institutional structures of the innovation system fulfil certain functions. However, this knowledge does not translate into a theory of wider transition dynamics; both TIS and energy system studies lack a dynamic theory of change. The MLP on the other hand is a heuristic framework to study such sociotechnical transition dynamics, and thus complement the other perspectives.

Third, it was necessary to understand the role and capacities of the state in enabling change, and the prospects of different policy designs, given that the ENRIs are often sheltered from regulatory pressure and operate on global competitive markets. Both energy system studies and STR give policy recommendations, but they are also often criticised for their lack of theories about politics, power and the state (see, e.g., [83,84]). As a complement, policy studies were introduced to better understand the conditions of decision-making processes as well as the role of state actors and institutions. For instance, studies by Hildingsson and Khan [70] and Hildingsson, Kronsell and Khan [71] have shown both the structural difficulties that the state faces when imposing stringent climate policies targeting core national industries, and the potential of policy change through dialogue and changes in the perceptions on decarbonisation within industries.

The perspectives discussed here do not cover all the relevant conditions for decarbonisation of the ENRIs. Power relations more generally (as studied in, e.g., political economy) are for example not well covered by any of the fields. We are aware of this, but the point of this exercise has not been to show comprehensiveness. What we have rather tried to show is that the three research fields of this study highlight different aspects of the problem and can potentially help resolve some of the limitations of the other fields. In other words, they are potentially complementary, but only if fruitful combination can be reached.

5.2. Not Easily Compatible

Although the different perspectives have been engaged in continuous dialogue throughout the GIST project, we realized the difficulties of establishing a common interdisciplinary analytical framework early on. While we believe in the necessity and fruitfulness of an interdisciplinary research approach, we are also much aware of the, sometimes, fundamental differences between theories, which makes it difficult to merge them into one common framework or interdisciplinary model. In the following, we discuss why we found them not easily compatible.

That different theories are not easily compatible is a result of their different ontological foundations. If they had the same ontological foundations, but studied different aspects of the same problem, interdisciplinary integration should not be too difficult. But with differing ontological assumptions, such integration is less straight forward. It can be achieved by either aligning theories with auxiliary hypotheses, or, where that is not possible, sublating more foundational tensions with a new synthesis that reconcile contradictory conceptions. It has been suggested that one procedural logic for doing so is that of immanent critique [80]. At its most basic, immanent critique is a method for identifying limitations and contradictions within a perspective and suggesting what might resolve them. This is, in a way, what Fuenfshilling and Truffer [45] did to the MLP. In its original formulation, the MLP lacks an endogenous conception of disequilibrium. Consequently, the regime has on occasion been criticised for being too ‘homogenous’ and ‘monolithic’. In the MLP, tension and disequilibrium emerge from exogenous landscape developments that create misalignment weakening the stability of the regime. By introducing the institutional logics approach, Fuenfschilling and Truffer introduce tension and disequilibrium as endogenous qualities of the regime, and at a same time create a bridge to institutional approaches to policy studies. A bridge made use of in the GIST project.

It is important to note that the three research fields in this study contain a plethora of approaches drawing on different paradigms. It is, in other words, not necessarily various research fields, or disciplines, that are incompatible with each other, but different approaches to those fields. There are, for example, structuralist, functionalist and constructivist approaches to both energy system studies, STR and policy studies. This makes it potentially possible to mix and match approaches—a certain approach to policy studies might, for example, be more compatible with STR than others.

Such integration, and mixing and matching, is, in other words, possible, but only potentially so. In reality, neither disciplines nor researchers are ontologically agnostic. Individual researchers tend to favour particular paradigms over others, and the ontological orientation of disciplines are often dominated by certain core assumptions that might differ. For example, even though both STR and energy system studies draw on system theory, they do so in different ways. What the elements are of a system, their nature, and how they interact differ significantly between different approaches. This also means that what gives stability to a system and what the dynamics of change are can vary considerably. At best, such differences highlight complementary aspects of what conditions decarbonisation. At worst, they present contradictory conceptions of systemic transformation.

Recently, discussions over how material properties condition transformation has been rife in the social sciences broadly. Material properties of course condition change in all transitions and sectors, but not the least in the natural resource-based industries where the spatial variability of biophysical conditions is of obvious importance. In the GIST project, Svensson [50] has sought to conceptualise and study how the material properties of specifically natural resources condition transitions. However, since transitions studies undervalue material properties, while ontologically privileging sociocognitive rules, some theoretical under-labouring was necessary. As a primer Svensson and Nikoleris [51] therefore conducted an immanent critique of STR, and in particular the MLP, to examine the limitations of its conceptualisation of structure and agency, and how it accounts for among other things material conditions. They found that since structure and agency are understood as inseparably instantiated in practise as sociocognitive rules, the causal influence of material conditions is in general misrepresented, and even altogether disregarded if not recognised by actors. Whereas Fuenfshilling and Truffer [45] found it possible to introduce disequilibrium as an endogenous quality of the regime by auxiliary hypotheses (possible since the institutional logics approach has a similar conceptualisation of structure and agency as the MLP), Svensson and Nikoleris [51] argued that adding theories of structure and agency that account for material conditions is theoretically inconsistent with the hard core of the MLP, i.e., its foundational assumptions. They therefore suggested new ontological foundations that would be able to account for both material conditions (as, e.g., biophysical characteristics of energy) and sociocognitive rules, rather than augment the MLP with further auxiliary hypotheses.

In conclusion, ontological alignment between different approaches is feasible where auxiliary hypotheses do not challenge the foundational assumptions, or the hard core of a research programme to express it in Lakatos terminology [81]. Fuenfshilling and Truffer's [45] extension of the MLP is an example of that. If theories on the other hand contradict each other with regards to the foundational assumptions, it is necessary to overcome such contradictions with a new synthesis that reconciles contradictory conceptions. Svensson and Nikoleris' [51] immanent critique of the MLP is an example of that. The procedural logic of immanent critique can help identify new conceptual directions that transcend such contradictions, but for Svensson and Nikoleris' suggestion to amount to a new interdisciplinary synthesis, further elaboration is nevertheless needed. To be clear, one mode of integration—aligning theories with auxiliary hypotheses or sublating foundational contradictions with a new synthesis—is not a priori better than the other. It depends on whether the result is theoretically consistent and enhance explanatory power or not.

In research projects, it is often not the case that work can wait until conceptual alignment or transcendence have been reached between all perspectives. This was also the case within the GIST project. Instead, a more incremental and processual approach is to aim for increased cross-disciplinary understanding through the use of boundary objects and concepts, as discussed below.

5.3. Towards a Processual Integrated Approach

In sustainability research, the emphasis on interdisciplinary research is strong, but it is not uncommon that pledges towards it have been frustrated as expectations and commitments are often higher than achieved outcomes [24]. Knowing this, and that we had ontological differences among us, we concluded that the most feasible way forward in our project was to aim for genuine/good multidisciplinary research that eventually opens up for higher levels of integration—a modest approach to integrated research as a developmental process (see, e.g., [85] with regards to integrated research as a developmental process).

What then do we mean by genuine/good multidisciplinary research? We mean research that is closely coordinated, not necessarily deeply integrated, but with strong cross-disciplinary understanding between project participants. In the GIST project, we did not simply synthesise at the end of the project, but rather had regular coordinating meetings (every to every other month) with discussions over results, what further problems are interesting and what additional studies are needed.

Beyond regular meetings, the project participants also worked on common reports and workshops, which allowed for collaboration without everyone sharing the same meta-theoretical orientation. For example, all the participants of the project collaborated around a report about the modern history of ENRIs and industrial policy in Sweden in order to examine the conditions for a new industrial policy for zero emissions ENRI [2]. Such boundary objects promote dialogue between researchers who frame a common problem, who get to know each other's perspectives by trying to integrate results, who scrutinise/review each other's work from different perspectives, and bring in multiple perspectives to inform governance of complex problems. This is not yet interdisciplinary work, since it does not integrate theories, but led to conclusions beyond what one would get from each perspective conducting these studies independently of each other (see Section 5.4).

Basic cross-disciplinary understanding was already established in previous collaborations between the project partners and furthered through regular discussions of results and problems at coordinating meetings and through collaboration around common reports and workshops but could have been developed even further with more systematic procedures. We think that one fruitful way of doing so is to work around certain shared boundary concepts. Although perspectives might differ in their core assumptions, boundary concepts can act as catalysts for interaction. They are concepts that are "weakly structured in common use", yet "strongly structured at individual sites" [86] (p. 12). As such they are negotiable entities that "simultaneously delimit and connect" [86] (p. 12). For example, the three research fields of this study share concepts that connect them, such as "lock-in", "path dependence", "pathways", "disequilibrium" and "non-linearity", but such concepts are often explained by different mechanisms and can have varying meanings in each field. By examining the conceptual tensions between different perspectives, with regards to concepts as these, cross-disciplinary understanding can be promoted. We also think that it is a fruitful way of opening up for higher levels of integration, such as interdisciplinary research. With this strategy, of strengthening cross-disciplinary understanding by examining conceptual tensions, integrated research becomes a developmental process that gradually questions ontological assumptions and promotes co-evolution of theories.

5.4. Broadening the Problem Frame

As Schmidt [18] argues, the framing of the problem is an essential part of problem-oriented integrative research. In the GIST project, integration of knowledge from different fields meant that the framing of the problem was broadened. The common report produced in the GITS project [2] concludes that the problem of decarbonising the ENRIs is broader than technological development, and goes beyond fiddling with innovation policy, or environmental policy, or energy policy.

The GIST report reviews how the character of industrial policy in Sweden has changed from general interventions in the economy during the 1950s and 1960s, to support crisis-ridden industries during the 1970s, and to market liberalisation and focus on innovation in recent decades [2]. Industrial policy has, in this process, become more fragmented and compartmentalised, which is problematic in a time when ambitious economy-wide measures are needed to counter the dual challenge of climate change and long-term industrial viability. The objectives of the Swedish government are grand—at the same time to decarbonise, reindustrialise, and become the first fossil-free welfare society in the world. But so far, limited progress has been made, and at too slow a pace, not only in Sweden but also globally. One of the reasons is that the problem is not understood and treated as a complex and multifaceted societal problem. To better understand this and adequately respond, an integrated approach is necessary.

Compartmentalised analysis of each domain—climate policy, innovation policy, energy policy, etc.—generally does not question the wider preconditions within which they are located. For example, it does not question the role of the state [71], or the role of other actors such as labour unions [87] in the transition process. Whereas industrial policy in Sweden over the last couple of decades has been restricted to innovation policy, the GIST report argues for a new industrial policy that makes decarbonisation of the ENRIs an integrated aspect of a broader politics for industrial development and societal change.

Broadening of the problem frame thus has normative implications. Indeed, integrated research and normativity are deeply intertwined as different paradigms frame the problem differently [80]. Ultimately, "the incorporation of various insights from a variety of disciplines is itself a normative question—i.e., which discipline (and even which particular paradigm within a discipline) ought we to seek out and incorporate?" [80] (p. 22).

Furthermore, the societal nature of problem-oriented integrated research makes interaction with societal actors important. To go beyond the conclusion of the GIST project and eventually propose what a broadened industrial policy could be, a further step up the integration ladder is necessary—transdisciplinary research that extends beyond synthetic integration of theories and involves "stakeholders and scientists in a joint project" [24] (p. 1102). Such a project could for example involve engagement with societal actors (as, e.g., trade unions and environmental movements) to examine what issues are important to them and how tensions and contradictions between the demands of different groups can be overcome. This engagement will include not only the question of decarbonisation but also other issues such as the long-term viability of ENRIs, distributional effects of the transition, and justice.

6. Conclusions

Decarbonising energy-intensive industries such as the ENRIs is a complex societal problem that is not simply associated with technological challenges but will require sociotechnical structural transformations. To understand the conditions for such transformations therefore necessitates integrated knowledge from multiple perspectives of different research fields. In this paper, we discuss the benefits and barriers of integrating perspectives from three different research fields employed in a concrete research project (GIST2050) and propose a modest approach to integrated research that is honest about what it takes to integrate research and avoids the seemingly common trap of virtue signalling, promising a lot but achieving little.

The three different fields of this study (energy system analysis, sustainability transitions research, and policy studies) are complementary—a fundamental condition for fruitful integration—but not easily compatible since their perspectives are sometimes based on different ontological assumptions. This makes it difficult to perform truly integrative interdisciplinary research without internal tensions and contradiction. Since it is seldom the case in problem-oriented projects that research can wait until conceptual alignment has been reached between all perspectives, our modest proposal is to work with integration as a developmental process that starts with good multidisciplinary research (coordination and cross-disciplinary understanding) while progressively moving towards interdisciplinarity (integration). We suggest that a central vehicle for this can be continually strengthened cross-disciplinary dialogue, understanding and examination of conceptual tensions.

The main conclusion of the GIST project was that decarbonisation of ENRIs cannot be framed as only a technological problem or simply a climate/environmental problem; it is a societal problem that needs to be addressed accordingly. In policy terms, this points to the need for a new kind of industrial policy aimed at a green transformation of the industry based on a broader understanding of the societal complexities involved. This implies a reorientation that goes beyond initiatives within single policy fields such as innovation policy or environmental policy, which in and of themselves are insufficient to elicit and support the transformative change required. Rather, what is needed is a broadened transformative industrial policy that does not simply pool initiatives from different policy fields but treats the problem as an integrated strategic issue. This conclusion, drawn from the GIST project, was the result of an integrated effort beyond what would have been found from studies within each field independently of each other.

Such a broadened transformative industrial policy is still not properly formulated, much less implemented, but there are calls for such development, most recently in the form of various propositions about a Green New Deal. Further research needs to engage with these developments and play an active role in its emergence, design and evaluation, with an ambition to provide an integrated understanding of the conditions for the sustainability transformations that lie ahead of us.

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