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The transition of energy intensive processing industries towards deep decarbonization: Characteristics and implications for future research

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ABSTRACT

Energy-intensive processing industries (EPIs) produce iron and steel, aluminum, chemicals, cement, glass, and paper and pulp and are responsible for a large share of global greenhouse gas emissions. To meet 2050 emission targets, an accelerated transition towards deep decarbonization is required in these industries. Insights from sociotechnical and innovation systems perspectives are needed to better understand how to steer and facilitate this transition process. The transitions literature has so far, however, not featured EPIs. This paper positions EPIs within the transitions literature by characterizing their sociotechnical and innovation systems in terms of industry structure, innovation strategies, networks, markets and governmental interventions. We subsequently explore how these characteristics may influence the transition to deep decarbonization and identify gaps in the literature from which we formulate an agenda for further transitions research on EPIs and consider policy implications. Furthering this research field would not only enrich discussions on policy for achieving deep decarbonization, but would also develop transitions theory since the distinctive EPI characteristics are likely to yield new patterns in transition dynamics.

1. Introduction

Energy-intensive processing industries (EPIs) are industries that convert natural resources into basic materials through processes that require high energy inputs. The EPIs included in this paper convert natural resources such as iron ore, bauxite, petroleum, lime stone, silicon dioxide and biomass into iron and steel, aluminum, chemicals, cement, glass and paper. These are essential material building blocks on which our society relies [1]. Globally, industry is responsible for over 30% of all greenhouse gas (GHG) emissions, of which the majority is emitted by EPIs [2]. Over the past decades, these industries have made significant resource and energy efficiency improvements [2,3]. However, meeting the EU 2050 emission reduction target of 80–95% compared to 1990 requires further, extensive low carbon innovation that is often of a radical nature [4,5]. The “well below 2C” target, recently adopted in Paris requires EPIs to decrease emissions to zero before 2070 [6,7]. Such deep decarbonization involves not only changes in technology through low carbon innovation, but requires a broader sociotechnical transition that also entails changes in user behavior, culture, policy, industry strategies, infrastructure and science [8–10]. However, this (deep) decarbonization transition at present proceeds at a very slow pace [11]. To facilitate and steer this transition process, more insight into the socio-technical drivers and barriers that affect the transition process is needed [5,12–15].

Studies employing sociotechnical and innovation systems (ST & I systems) perspectives have provided valuable insight into the socio-technical drivers and barriers to the development and diffusion of new, low carbon technologies and practices, and in understanding the lock-in of existing regimes around established, carbon-intensive technologies. These insights have shaped public policy to more effectively facilitate and steer sustainability transitions [16–19]. Empirical analyzes of sustainability transitions have so far, however, focused on the energy, buildings and transport sectors and have insufficiently studied sectors like EPIs, where such insights could help stimulate the decarbonization transition. This study aims to position EPIs within the transitions literature to develop such insights.

There is also a theoretical contribution to studying EPIs from an ST & I systems perspective. The few transition studies that focused on

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EPIs, including the tile [20], paper and pulp [21,22], steel [23] and cement and concrete industries [24,25], show that many barriers to low carbon innovation result from distinctive EPI characteristics. The lack of demand for cleaner basic materials, for example, may be related to EPIs being far removed from the end-consumer, while regulatory pressure is affected by the fear of disadvantaging domestic industries in a highly globalized and price competitive commodity market. These distinctive ST & I systems characteristics provide opportunities for theoretical enrichment of the transitions literature, for example by identifying new transition dynamics or lock-in mechanisms [25].

By positioning EPIs within the transitions literature and by providing a research agenda, this paper broadens the empirical application of the literature's theoretical concepts and enables future work to develop these concepts and to formulate more effective policy recommendations on facilitating and steering the transition in EPIs towards deep decarbonization.

This paper is structured as follows. Section 2 discusses the theoretical framework and methods. Section 3 first systematically describes the characteristics of ST & I systems in EPIs with stylized facts. Subsequently, Section 4 reviews, based on the limited data available, how these stylized facts may affect decarbonization transitions in EPIs and specifies an agenda that identifies fruitful venues for further transitions research on decarbonization of EPIs. We refer to a decarbonization transition instead of a sustainability transition, because we are primarily interested in climate related sustainability. The paper is concluded by reflecting on the emerging field of decarbonization transitions in EPIs and by providing policy implications based on existing knowledge.

2. Approach

2.1. ST & I systems perspective

Different approaches have been developed to study sustainability transitions, including the multi-level perspective, strategic niche management, transitions management, and sectoral and technological innovation systems perspectives. What these perspectives have in common is that they study the emergence, functioning and transitioning of ST & I systems. The goal of these systems is to develop and diffuse innovations and goods to meet current and future societal demands. They are comprised of structural components that include actors (firms, trade associations, government, research organizations, consumers, etc.), institutions (such as norms, values and formal policies or regulations), technologies or materiality (such as plants, infrastructure) and the interactions between system components. The systems can be delineated to the societal functions they fulfil (i.e. a socio-technical system) or to specific technologies, sectors, regions or nations (i.e. different types of innovation systems).

ST & I systems develop or transform through the co-evolution of system components as innovation cannot take place in a vacuum [26]. Exogenous factors like climate change may trigger new societal demands, such as environmental sustainability, that drive the existing ST & I system to change in ways that accommodate the new societal demand. Depending on the force of the exogenous factor and the stability of the ST & I system, this systems change involves a transition along existing technological trajectories (such as the development of energy efficiency improvements) or the transition to a new system configuration that revolves around new (low carbon) technologies [27]. Some system components or misalignment between components may (purposefully or not) inhibit the development and diffusion of new technologies or frustrate the transition process (so-called system problems, failures or bottlenecks). Policy makers aiming to facilitate or steer system growth and transition, should focus on overcoming these system problems [28,29].

To understand technological change in EPIs, this paper distinguishes between incremental innovations that follow existing technological trajectories, and radical innovations that constitute new technologies. Utterback [30, p. 200] defines radical innovation as “change that sweeps away much of a firm's existing investment in technical skills and knowledge, designs, production technique, plant and equipment”. For EPIs this definition typically means investing in novel technologies for the basic conversion process or for changes in feedstocks.

To understand the dynamics of the decarbonization transition in EPIs, this paper also distinguishes between innovations that range from marginal to significant (described as low carbon innovation) GHG emission reductions. These innovations may reduce emissions purposefully or not (sometimes emissions reductions are only a co-benefit, for example of energy efficiency and recycling), as well as directly (e.g., emission capture) or indirectly (e.g., lower electricity demand).

We use the structural components of ST & I systems and the aforementioned innovation typology to structure our discussion of the factors that influence the innovation processes in EPIs (in Section 3) and of how this may affect the transition to deep decarbonization (in Section 4).

2.2. Research design

To position EPIs within the transition literature, this paper first characterizes the ST & I system of EPIs with stylized facts. Stylized facts are broadly generalized and simplified representations of empirical findings. To come to these stylized facts, we have gone through a series of research activities aimed at co-developing and inventorying knowledge between the six authors, which include experts in the field of innovation and transition studies and experts in the field of EPIs. These research activities are listed in Table A.1 in the Appendix and include explorative discussions, two questionnaires and three workshops intermitted by consecutive rounds of coordinated writing and triangulation with documented sources. Such triangulation was however not always possible due to limited and often technology or sector-specific documentation. The years of research, including interviews and working with EPIs, by the EPI experts provides a basis for understanding the key characteristics of these industries and their innovation dynamics that extends beyond what can be found based on documented data and scientific literature. For the purpose of identifying EPI-overarching stylized facts, this research approach is deemed more suitable than relying on the limited existing documentation alone.

After characterizing the ST & I systems of EPIs with stylized facts, we review the literature and documentation on EPIs to infer how these stylized facts may influence decarbonization transitions. The literature gaps identified in this process are formulated into a research agenda that aims to inform and stimulate future transition studies on EPIs.

Our subsequent discussion of the EPI characteristics and implications for decarbonization transition is structured by the ST & I system components identified as the most important; they include industry structure, corporate innovation strategies (which are influenced by and reinforce the industry structure), networks, basic material markets and government policy.

3. Characterizing the ST & I systems of EPIs: stylized facts

Fig. 1 provides an overview and describes with stylized facts, the most important actors, networks and institutions that characterize ST & I systems of EPIs and embeds these systems within the larger value chain. This overview shows that EPIs are very different from the energy, buildings and transport sectors conventionally studied by the transition literature, not only in terms of their position along the value chain, but also in their ST & I system characteristics. The remainder of this section further discusses the stylized facts that capture these characteristics, followed by a reflection on their differences between EPIs (in Section 3.6).

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