



Exploring the re-emergence of industrial policy: Perceptions regarding low-carbon energy transitions in Germany, the United Kingdom and Denmark

Phil Johnstone^{a,*}, Karoline S. Rogge^{a,b}, Paula Kivimaa^{a,c}, Chiara Farné Fratini^d, Eeva Primmer^c

^a Science Policy Research Unit (SPRU), University of Sussex, BN1 9RH Brighton, UK

^b Fraunhofer Institute for Systems and Innovation Research ISI, Karlsruhe, Germany

^c Finnish Environment Institute (SYKE), Helsinki, Finland

^d DTU Environment, Technical University of Denmark, 2800 Kongens Lyngby, Denmark

ARTICLE INFO

Keywords:

Industrial policy
Energy transition
Policy style
UK
Denmark
Germany

ABSTRACT

Industrial policy has re-emerged as an area of policy discussion in recent years, but the characteristics and role of industrial policy vary across national contexts. Particularly, the role of industrial policy in the ongoing energy transitions of different countries has received little attention. We introduce an analytical framework to explore the relationship between industrial policy and different energy policy trajectories and apply this framework in an empirical analysis of the perceptions of key stakeholders in the energy sector in Germany, the United Kingdom and Denmark. We identify four key elements of industrial policy – industrial visions, industrial policy instruments, industrial policy governance, and employment concerns – and based on these analyse perceptions of how industrial policy has facilitated changes in the energy system of the three countries. We find significant differences in industrial policy styles for low-carbon transitions, reflecting broader differences in political institutions and cultures. Our analysis shows how sustainability transitions relate to industrial policy, and which elements can act as enablers and barriers to low-carbon transitions.

1. Introduction

Industrial policy has been defined as “structural policies designed to strengthen the efficiency, scale and international competitiveness of domestic industrial sectors, typically containing an element of national champions, of self-reliance in bringing about growth and development” ([1]: 273). After some absence, industrial policy has re-emerged in policy analyses and debates during the past decade [2,3]. The re-emergence has been labelled variously as a ‘return’ [4], ‘renaissance’ [5], ‘rejuvenation’ [6], ‘reinvention’ [7], ‘resurrection’ [8], and ‘resurgence’ [9].

While industrial policy has had some overlap with innovation policy through the search for the sources of domestic competitiveness, much attention has in the past focused on supporting existing industrial processes. The re-emerging industrial policy differs from the past in perhaps two respects. One, new industrial policy is more closely connected to innovation policy, emphasising regional economies and place-based

characteristics, diversification of industrial structure, and entrepreneurial discovery – argued to lack a normative stance [2]. Two (partly contrary to one), green industrial policy has emerged as a notion making an explicit connection to environmental objectives [10,11]. Green industrial policy, broadly defined as “government intervention to hasten the restructuring of the economy towards environmental sustainability” ([12]: 522), has limited grounding in the traditional industrial policy literature [13]. A key aspect of green industrial policy is shifting economic trajectories away from traditional industries towards new, ‘greener’ technological industrial futures, for example, by expanding industrial capacities around renewable energy manufacture [10,14].

This paper connects the notions of industrial policy and green industrial policy to the literature on low-carbon energy transitions, drawing from the field of sustainability transitions. Sustainability transitions address large-scale transformations in socio-technical systems, such as energy, mobility, water or food, reducing their negative environmental impacts. Transition studies focus on socio-technical change,

* Corresponding author.

E-mail address: p.johnstone@sussex.ac.uk (P. Johnstone).

<https://doi.org/10.1016/j.erss.2020.101889>

Received 8 June 2020; Received in revised form 14 November 2020; Accepted 8 December 2020

Available online 2 March 2021

2214-6296/© 2020 The Author(s). Published by Elsevier Ltd. This is an open access article under the CC BY license (<http://creativecommons.org/licenses/by/4.0/>).

having an interest in changes in practices, routines, culture, policy and institutions alongside and intertwined with technological change [15,16]. Much empirical attention has been paid to energy transitions, grounding the conceptual development of this literature [17]. Industrial policy is a relatively recent consideration in this literature [18] and mostly addressed in passing [19]. This can be regarded as somewhat surprising given that attention to public policy in transitions has received increasing interest [20] and industrial dynamics are a part of transforming socio-technical systems [21].

In sustainability transition studies, a key focus has been placed on how the nurturing and empowerment of new niche technologies lead to the destabilisation of unsustainable socio-technical regimes, typically for a particular focal sector such as energy [22–24]. In such accounts, the focal system in question is guided by the aims of achieving environmental sustainability, yet broader motivating factors to do with industrial transformations involving issues of employment, ‘up-stream’ activities in manufacturing, value creation and trade patterns have so far been largely neglected in sustainability transitions studies [25]. Bringing an industrial policy lens to bear on sustainability transitions research is not only important for enhancing empirical and conceptual understandings of the broader factors that influence socio-technical transitions, but can potentially also play an important role in enhancing the feasibility of sustainability transitions through creating new industrial opportunities and minimising disruption [25,26].

Indeed, there are an increasing number of perspectives in energy debates and elsewhere that advocate that a form of green industrial policy is required for more rapid and just sustainability transitions to be realised [10,27–29]. With current policy discussions around a Green New Deal in both the USA and Europe [30,31] this position has become a fairly ubiquitous one around sustainability transitions. We find these arguments convincing and given the scale of the transformation required to meet CO₂ emissions reductions targets across multiple systems [32], sustainability transitions will require significant industrial transformation. However, while we have witnessed a variety of proposals for green industrial policies, so far there has been little attention in the sustainability transitions literature on what the role of industrial policy has been so far in transition processes. Additionally, there is a need to guard against a ‘one size fits all’ approach to industrial policy, and to appreciate the ‘variety’ of industrial policies in different national [33] and regional [2] contexts. This present analysis contributes to such an understanding.

Empirically, we examine the perceptions that key stakeholders have had regarding the role of industrial policy in the low-carbon energy transitions of Germany, the UK, and Denmark. Based on our analysis, we discuss whether and how issues arising from these transitions may have influenced the ‘re-emergence’ of industrial policy in the European context. All three countries have seen a rapid increase in the share of renewables as energy sources in the electricity generation mix and, to a lesser extent, the energy mix. In 2019, renewable sources accounted for 46% of electricity produced in Germany [34], 36.9% in the UK [35], and 72% of in Denmark [36]. Yet, the technologies prioritised in the respective transitions and the implications and role of industry, jobs and skills in these transitions differ.

Industrial policy can be characterised with certain fluidity and difficulties to draw exact boundaries, especially in cases where industrial policy has been left implicit and is realised via other sectoral policies, such as energy and innovation. Thus, our approach is exploratory in nature, seeking to shed light on industrial policy related factors and their role in the respective energy transitions by drawing on semi-structured

expert interviews. First, we explore the different styles of industrial policy in the three case studies (RQ1). Second, we examine whether and how industrial policy has been perceived to *enable* or *hinder* low-carbon energy transitions (RQ2).

Section 2 outlines the conceptual background on industrial policy literature and sustainability transitions, followed by our proposed analytical framework based on these literatures. Section 3 describes the empirical method. Our findings are presented in Section 4. Section 5 discusses these findings regarding the different patterns of industrial policy for low-carbon transitions in each country. We then discuss the observed differences against sustainability transitions literature and the usefulness of the industrial policy lens.

2. Conceptual background

2.1. Industrial policy

2.1.1. Traditional industrial policy and its rejuvenation

Industrial policy is a broad term capturing different manifestations and forms of policy intervention [37,38]. At its broadest, industrial policy has been defined as “...a variety of public actions aimed at guiding and controlling the structural transformation process of an economy” ([39]: 3), and, more specifically, “policies by which governments attempt to shape the sectoral allocation of the economy” ([40]: 43). Industrial policy can be explicit or implicit, intentional or unintentional but, in effect it has typically meant that certain industries are favoured more than others [6]. Most countries pursue industrial policy through “any government decision, regulation or law that encourages ongoing activity or investment in an industry” ([41]: 23). In practice, this is likely to require elements of policies, such as visions, instruments and coordinated governance in different policy domains, such as educational, innovation, economic and financial policies, allowing industries to develop “economies of scale and become lowest cost producers” ([41]: 25).

The term industrial policy is a controversial one [4], stemming partly from fuzzy definitions, varying scope, normative questions, and differing applications between countries [39,41]. As Bosch ([42]: 7) argues, despite its resurgence, industrial policy is an ‘elusive’ term as “[u]nlike monetary policy, competition policy or trade policy, ‘industrial policy lacks a clearly identifiable set of goals, policy instruments and institutions, such as a legislative framework to delineate the scope for industrial policy or designated agencies to execute it.’” Indeed, we argue that industrial policy cannot be easily discerned through a simple identification of stated industrial policy but must be looked at in terms of identifying those policies, or mixes of policies, which may be of relevance to the aim(s) of industrial policy. As such industrial policy lends itself to be systematised through the lens of policy mixes [43], with instrument mixes comprising both ‘vertical’ sectoral interventions and ‘horizontal’ ones overlapping different policy domains and a broad range of actors. In addition, when it comes to ‘mission oriented’ industrial policy strategies [46], long term ‘guiding visions’ around shared goals and challenges are another crucial component in coordinating industrial development and transformation.

Many facets of industrial policy are inspired by insights from the innovation systems approaches [47]. For example, some accounts of industrial policy pinpoint innovation policy and long-term strategic R&D support as key components of industrial policy [48]. Other examples concern the importance assigned to industrial clusters [49] and regions [2], collaborative links with research institutions and industry

[50], and coordination of industrial relations by governments [51]. These are all factors that are recognised as important in national innovation systems approaches [52], explaining overlaps between industrial and innovation policy.

National approaches towards industrial policy vary greatly. Andreoni ([33]: 246) states that “[t]he variation in countries’ industrial policy experiences is driven by their contextual — institutional and structural — and political economy differences as well as by the different policy space and rationales for government action.” Industrial policy varies in how industries are accounted for in regional and national strategies; the role and type of finance (e.g., in the presence of local and national banks); education and skills training policies; export-oriented policies; innovation policy such as public R&D support; and the role of trade unions in decision making. Thus, comparing industrial policies involves examining factors that relate to ‘varieties of capitalism’ literature [53,54].

The degree to which industrial policy has been used explicitly by policy makers is influenced by the broader economic context. Arguably, industrial policy fell somewhat out of favour from the 1980s onwards with the rise of ‘neoliberalism’ as a dominant form of economic ideology, with industrial policy seen as a part of ‘inefficient’ government practices of ‘picking winners’. This gave way to privatisation and deregulation policies leading to increased governance through market mechanisms with ideological commitments for a minimal role for the state.

However, as noted above, in the wake of the financial crisis of 2008, the renewed interest in industrial policy has been driven by two main factors. First, a *need to re-stimulate growth and employment* as a response to the economic crisis raising concerns over structural imbalances in the economy and the prevalence of market failures, recognising the political economy of market bail-outs, and the success of the emerging market economies [55]. Second, a *number of societal objectives*, such as moving towards low-carbon and resource efficient societies, have been connected with the creation of a learning economy, addressing distributional issues and promoting employment [6]. For example, European Union (EU) industrial policy has been reconsidered in response to unemployment and the decline of manufacturing [56] and given a recent sense of urgency in the context of economic recovery from the coronavirus pandemic [57]. Further increasing interest towards mission-oriented innovation policy with potential to address societal challenges, such as accumulating plastics in oceans can be seen as a new boost for industrial policy [58]. As an example of the combination of these trends, the challenge of climate change has been coupled with opportunities to bolster employment and manufacturing around low-carbon innovation [59].

2.1.2. Green industrial policy and energy transitions

In recent years, discussions around ‘green industrial policy’ have become increasingly prolific [11,27,60–62]. The idea is to promote more eco-efficient technologies addressing an environmental problem, while simultaneously bolstering competitiveness to deal with economic problems associated with deindustrialisation [63]. Indeed, energy transitions, entailing the adoption of new technologies and with long-term implications for the broader economy have been identified as being an important domain where ‘green industrial policy’ planning and intervention is required [12]. Green industrial policy seeks to build new industrial trajectories around the green economy and, thus, explicitly addresses environmental policy objectives. There is a recognition that green industries are often ‘infant industries’ that require additional

support before they can become competitive with dominant technologies [64]. In this setting, strategic and coordinated industrial policy that supports green technologies and mitigates and manages labour market processes is seen as crucial [65]. For example, as low-carbon energy transitions gain momentum, industrial policy can help prepare for new kinds of jobs and skills that become necessary following the closure of carbon-intense incumbent industries.

Pegels and Lütkenhorst [12] define green industrial policy as “government intervention to hasten the restructuring of the economy towards environmental sustainability” and outline four factors of importance: inducing innovation, creating jobs, mitigating climate change, and minimising cost to consumers. They point out that international trade is a key consideration, with tariff protection, favourable customs and excise taxes, and ‘local content requirements’ representing potential instruments for protecting domestic manufacturing and fostering internationally competitive industries. A variety of policy instruments has been identified as green industrial policy. For example, Schwarzer [14] differentiates between regulatory and control mechanisms, environmental taxes, industry protection, and industry support mechanisms.

While policy mixes have been acknowledged to play a key role in governing sustainability transitions [20,66], industrial policy is seldom explicitly mentioned. However, through attention towards ‘creative’ and ‘destructive’ instruments in policy mixes [67] and ‘destabilisation’ of incumbent industries [24], more structural and directed processes of industrial change benefit of industrial policy are gradually emerging. An example in this regard is the deliberate ‘phasing out’ or discontinuation of unsustainable technological trajectories [69].

There is some overlap therefore between the focus in sustainability transitions on promoting novel socio-technical developments through protection, nurturing, and the creation of new markets around for example, wind or solar technologies [70] and green industrial policy. However, there are also differences in terms of scope, goals, and dimensions. Sustainability transitions have tended to focus on downstream activities in a particular focal system and on promoting sustainable niches, a variety of actors, vision building from the perspective of sustainability and bottom-up developments. In transitions, policy is only one of the system dimensions hindering or promoting transitions. Instead, industrial policy has more emphasis on coordinated and long-term action by the state and is more attentive to ‘upstream’ activities like manufacturing and ‘inter sectoral’ issues (for example, the implications of energy transitions for heavy industries) [25]; the goals are directed towards broader aims of creating a strong economy through job creation and retention, enhancing skills capacities, trade opportunities, and this reflects a broader set of dimensions under consideration where new actors are brought to the fore such as trade unions that have traditionally been neglected in sustainability transitions research [71]. However, the two are increasingly connected by a growing attention in advancing transitions to phasing out incumbent and polluting industries [72] and a need for transformative [73] and mission-oriented policies [58] across sectors having an impact on the state of the environment. In the next section we expand on the elements of industrial policy we draw on to conduct our analysis.

2.2. Elements of industrial policy

In this research, we are not comparing the industrial policies of different nations in terms of a comprehensive literature-based or economic evaluation as other studies have done [33,74]. Instead, we

examine what perceptions energy system actors have of the role that industrial policy has played in low-carbon energy transitions. To do so, we build on and identify a broad set of elements from the comparative work on “varieties of industrial policy” [33]. Given the well-recognised difficulties to identify a particular domain or set of policies that definitely constitute ‘industrial policy’ [42] and the recognised broader role of political cultures in shaping industrial policy [75], these elements enable a broad country comparison regarding different industrial policy styles.

Varieties of industrial policy is a framework that “...reveals and contrasts emerging patterns and trends in industrial policy practices” ([33]: 246). Focussed on the energy system, we do not go into the same level of detail as Andreoni, but rather build on the varieties approach to construct broad elements that are best suited to a comparative perspective and that are flexible enough to accommodate responses from interviewees in a semi-structured manner. We therefore refer to industrial policy styles in energy systems, which can be defined as *the contrasting patterns of industrial visions, industrial policy instruments, industrial policy governance, and employment concerns and their perceived significance in energy transitions*. We now discuss each of the elements that contributes to our focal point of interest in industrial policy styles.

Three dimensions focussed on by Andreoni to compare the industrial policies of countries include ‘policy synchronisation and policy cycles’, ‘policy packages’, and ‘policy governance models and coordination’. ‘Policy synchronisation and policy cycles’ entails attention on the challenge of “synchronizing policies over time within each transformation cycle” ([33]: 261). A transformation cycle involves a set of long-term policies that transcend different governments. Andreoni highlights that fundamental to synchronisation over this time period is coherence and a key structuring component of this coherence is the extent to which there is a coherent vision over the period of a transformation cycle. This question of vision is key to industrial policy discussions. As Chang et al. point out, “one thing that comes out strongly through the review of industrial experiences in other countries is the importance of the national vision” ([76]: 46). Meanwhile, Mazzucato highlights the importance of a vision for industrial policy and the need for the state to “...provide the direction towards new “techno-economic paradigms”, which do not come about spontaneously out of market forces” [46] (122). The transformation cycle relates to ‘transitions’ and the concerted shift towards clean energy transitions that emerged in the 1970 s and 1980 s. We are interested in the perceptions of interviewees in the extent to which there has been a coherent long-term vision with regards to the clean energy transition (entailing technology/component production and energy production from clean energy sources) in each country and the extent to which an industrial vision has been a part of the clean energy transition. We refer to this element as *industrial visions*.

Second, Andreoni [33] identifies “policy packages” to compare industrial policies entailing the different instruments that can constitute industrial policy ranging from vertical interventions for particular sectors or technologies such as direct subsidies or educational policies, to horizontal policies such as establishing multi-actor trade platforms around industrial growth [33,49,74]. The fuzzy definitions and cross-cutting nature of industrial policies make this an issue that is notoriously difficult to pin down given that certain ‘energy policy’ interventions could also be part of an industrial agenda [12]. Similarly, there are striking similarities between national innovation policies and industrial policies [77]. This is a complex area for which we cannot go into to detail in this paper. For the purposes of the present analysis

Table 1

Interviewees per category in Germany, UK, and Denmark.

Actor type	Number of interviewees			Total
	Germany	UK	Denmark	
Policy makers (incl. civil service)	3	4	7	14
Industry associations, utilities	5	5	6	16
Research, consultants	5	1	4	10
Think tanks, NGO, trade unions	2	3	3	8
Total	15	13	20	48

however, we follow Andreoni in recognising that instruments from ‘innovation and technology policies’ constitute an industrial policy package [33]. A certain sub-set of policies, for example those aiming to create new regional industries, can be regarded as industrial innovation policy [2]. We refer to the element of *industrial policy instruments* when discussing and evaluating interviewee perceptions of what policies within energy are understood to be implicated in industrial policy. However, we also note the option of an industrial policy component of energy policy.

Third, we draw on Andreoni’s focus on ‘policy governance models and coordination’ which is used to compare how industrial policies can vary based on whether policies are centrally planned at the national level or more decentralised among federal governance levels and a plurality of regional or state actors [33]. Municipalities and cities can also have a role in industrial policy formulation [78,79]. This element relates to broader differences between respective ‘qualities of democracy’ and the degree to which decision-making is centralised or decentralised in a particular country [80]. We refer to the element of *industrial policy governance* to interrogate the perceptions of stakeholders with regards to how industrial policy enacted in the energy sector is facilitated based on these governance considerations.

Andreoni also draws attention to a key policy instrument aimed at ‘workers training’ [33]. Elsewhere, those writing on industrial policy in relation to energy have highlighted the importance of job creation and retraining as a prominent factor in energy transitions [12,71]. The element of *employment concerns* thus places attention to the extent to which job creation and sustaining skills in manufacturing or other sectors play a role in a country’s energy transition. This focus on jobs is a central element of green industrial policy alongside the promotion of environmental technologies [81,82]. A distinguishing feature of energy policy having industrial policy dimensions is the existence of instruments put in place to utilise energy transitions for new job creation, skills retention, and ensuring positive benefits for manufacturing sectors and industries [12,83]. ‘Green industrial policy’ aims at garnering competitiveness, future skills, manufacturing and employment opportunities from clean energy transitions [84]. Furthermore, trade unions and their relative power in policy making processes can be important in determining the degree to which employment and skills are considered with regards to European energy transitions [33,74]. This can also be useful for comparing the industrial policy influence on respective national energy policies. We propose the element of employment concerns as a distinct one from more general industrial policy instruments to respond to the specific challenge of how to distinguish between energy policy and industrial policy. We argue the approach above provides a prudent means of ascertaining the degree to which considerations beyond just energy policy goals and related to industrial policy goals influence energy policy, enabling a parsimonious means of comparison.

Table 2
Summary of industrial policy elements in low-carbon energy transitions.

	Germany	UK	Denmark
Overall role	Energiewende only partially regarded as industrial policy; conflicts between traditional and green industrial policy	Industrial policy not recognised by interviewees as playing a significant role in energy transition, yet offshore wind and nuclear policy appear to be partially driven by industrial policy concerns	Purposeful creation of new industrial base around wind industry, and parallel phasing out of coal industry
Industrial visions	Long-term vision towards a low-carbon, renewable energy system (without nuclear) includes competitiveness as primary objective; yet limited industrial vision regarding green industrial policy.	Perceived lack of industrial vision regarding a new low-carbon energy system; yet nuclear and offshore wind prioritised, fitting with centralised vision of energy production.	Strong long-term vision of energy transition and its potential for industrial growth, initiated by the Alternative Energy Plan with strong leadership by key politicians in the 1990s committing to this vision.
Industrial policy instruments	Co-existence of instruments protecting existing (energy-intensive) industry and support for renewable energy industry.	Characterised by short-term chop and change policies, for many renewable energy sources and innovation. Contracts for Difference and 'local content requirements' for offshore wind; 35 year 'strike price' for new nuclear.	Mix of subsidies, taxes and employment and innovation focused instruments.
Industrial policy governance	Strong regional but also national responsibilities.	Centralised decision making with a lack of regional industrial policy and regional political control more generally.	Municipal and regional focus recently replaced by re-centralisations.
Employment concerns	Job creation in green technologies seen as one of several benefits of Energiewende, but also attention to job losses in polluting industries; Pro-transition and against-transitions trade unions.	Employment not seen as a significant part of energy transition policy and discussion in the UK; trade unions not actively part of energy transitions.	Job creation and reskilling initiatives seen as an important driver in Danish energy transition; trade unions actively involved via political strategies aiming for just transitions.

3. Research method

We adopted a comparative country case study approach [85] to understand the interplay between industrial policy and low-carbon energy transitions via actor perceptions. Our principal research approach was an analysis of stakeholder perceptions of industrial policy and energy transitions in the case countries. Analyses involving different stakeholders are particularly suited to public problems that interconnect different sectors, people and organisations [86]. In this case, the analysis of perceptions was found more suitable than document analysis, as industrial policy, albeit existing in many countries in one form or another, is frequently implicit at the absence or in addition to formal industrial policy. As we noted earlier, industrial policy can be operationalised via policies labelled as innovation, education and even energy policies. We, thus, relied on the identification of knowledgeable experts in each country in the interface of industrial and energy policy, and their perceptions of which policy goals and means can be accounted as industrial policy pertaining to the energy sector in their countries. Stakeholder perceptions reveal the image, cognitions and frames of reference that actors have about the policy and policy problems [87]. Thus, differing perceptions are likely to occur, while we undertake the more frequent occurrence of similar perceptions between interviewees to provide evidence of a stronger finding of relevant policy issues.

In-depth interviews were used as a primary data source, and academic literature and policy documents as supplementary data sources. A semi-structured interview guide was developed by the author group. Altogether 48 expert interviews were conducted during November 2016 – March 2017 (see Table 1), conducted by three of the authors, each responsible for one country. Interviewees were selected to represent expertise in the energy sector covering different actor groups, including civil service and politics, utilities and industry associations, researchers and consultants, as well as non-governmental organisations, think tanks and trade unions. The interviews lasted 45–95 min and were recorded and transcribed. All non-English interview transcripts were translated into English.

For each case study country, we also conducted a literature review on industrial policy and energy transitions. This resulted in a list of over 30

peer-reviewed articles and reports, comprising contextual background information and enabling the triangulation of emerging research findings. The time period under consideration is flexible given that exact timings of low-carbon energy transitions differ between countries and we were guided by interviewee interpretations of key events with regards to industrial policy and low-carbon energy transitions. However, with regards to data from the literature, we did not include information prior to the oil shock of 1973, as this is widely used as a critical juncture when discussing low-carbon energy transitions as it was after this point that many governments and other organisations explored alternative sources of energy more purposefully [88].

An initial coding framework was developed drawing on the literature review and refined based on initial interview analysis. This refinement was accomplished by four authors coding one interview individually, followed by a joint comparison of coding. This resulted in some alterations to the list of codes and improved the interpretation of codes. To enhance the reliability of our analysis, we conducted two further rounds of comparative coding until a satisfactory level of mutual understanding of the codes and the coding procedure was achieved within the author group and a final list of codes was agreed upon. Subsequently the first author coded all transcribed interviews in NVivo.

Following an initial coding and preliminary analysis of the interviews, the most frequently used codes were selected for more systematic analysis using Excel. The first author summarised the key insights from each interview per selected code, also forming an interpretation of the findings per code. Then, two other authors formulated their own interpretation for each code, allowing discussion regarding differing interpretations and meanings. Through this process, we generated a joint interpretation of overall findings for each country.

As described above, we triangulated and complemented our interview findings with the empirical literature. In a final analytical step, we focused on deriving the bigger picture and identifying overarching findings regarding our research questions.

4. Findings

In this section, we present our findings. We start by examining the

status of low-carbon energy transition and industrial policy in Germany, the UK and Denmark (Section 4.1). We then focus on actor perceptions of the role of industrial policy and its different elements on the low-carbon energy transition in each country (Section 4.2). Finally, we consider how industrial policy has been perceived both as an enabler and potential barrier to low-carbon energy transitions (section 4.3).

4.1. Status of industrial policy

For Germany, perceptions of the role that industrial policy plays more generally, definitions of what constitutes industrial policy, and the role of green industrial policy varied considerably among the interviewees. Yet, in the UK, Germany is often cited as an exemplar country of successful industrial policy [89], and prominent economists note that “it is fair to say that it [Germany] has one of the most active industrial policies in Europe” ([76]: 28).

Four interviewees highlighted the broader issue of openly using the term ‘industrial policy’ in the German context. For example, industrial policy was highlighted as a “controversial paradigm - not controversial in doing so, but controversial in naming it” (DE11, Research). Similarly, it was referred to as a “very ideologically loaded term” (DE5, Think Tank). Another interviewee explained that “one has to be very careful” in using the term industrial policy given the high political value placed on the idea of a ‘free market’ (DE4, Utility). Yet another interviewee highlighted that politicians in Germany are “fearful” about stating they are pursuing an industrial policy in case it appears they are selecting “technological winners and losers” (DE3, Research). In effect, innovation policy was said to often be preferred as a term over industrial policy, while there “is still industrial policy behind.” (DE11, Research).

For the UK, there was a perception shared between five interviewees that, for the past several decades, the UK has effectively had no industrial policy: “I’m not convinced there really has been industrial strategy in the UK for probably kicking on for certainly more than my lifetime.” (UK2, Politician) and “the traditional British view, at least since the optimism of the ‘60 s, has been: ‘We don’t do industrial policy. It just messes things up’” (UK1, Research). This perceived lack of industrial policy and instead the dominance of a market-oriented approach is also recognised in the literature [90,91]. However, since the financial crisis of 2008, Berry [92] points out that there have been renewed policy discussions on industrial policy around concerns for ‘rebalancing’ the British economy, to address the decline of manufacturing, poor productivity and regional inequalities. Such issues have been under discussion to some extent by the Labour Party in 2009 and the coalition government since 2010. This has culminated in the elaboration of an explicit Industrial Strategy which was published in December 2017 [93] and was strengthened by discussions around the UK’s future in the context of Brexit, thereby putting industrial policy centre stage, including in the name of the responsible ministry ‘Department for Business, Energy and Industrial Strategy (BEIS)’.

Danish interviewees perceived that industrial policy had played a significant role in recent Danish energy transitions which is discussed in section 4.2.3. More broadly, Denmark is clearly identified as a country where in the 1970 s and 1980 s, “a revitalization of industrial policy” took place involving “...a greater directive role for the government” ([94]: 6). Campbell and Pedersen ([95]: 321) argue that “...Denmark embraced industrial policy” where, due to lacklustre performance of the Danish economy in the 1970 s, “the government devised an industrial policy aimed at improving the technological capacities and, therefore, the competitiveness of Danish firms in world markets”. However, this was fundamentally oriented around the kinds of procedures of ‘negotiative democracy’,

comprising “an institutionalized strategic collaboration between various actors from the private sector and government—a discovery process where firms, unions, other interest groups, experts, and the state learn about costs and opportunities and then engage in strategic coordination” (ibid: 323). It is worth emphasising that such a policy approach stands in stark contrast to the former market-driven approach of the UK [50].

4.2. Perceived role of industrial policy and its elements in low-carbon energy transitions

We now turn to presenting our findings on stakeholder perceptions regarding the role of industrial policy in low-carbon energy transitions in Germany, the UK and Denmark, differentiating between the elements of industrial policy set out in section 2.3. For each country we summarize the key points in Table 2 and provide illustrative quotes in the Annex.

4.2.1. Germany

Interviewee responses regarding the role that industrial policy has played in the German energy transition were nuanced but can be divided into two broad perspectives. One perspective was that the German energy transition was an example of green industrial policy through stimulating German industry towards a green economy (five interviewees). For example, one interviewee noted that the role industrial policies had played in the Energiewende was “a very central one”, where the government had intervened to “deliberately build up an industry” (DE3, Think Tank). This is in line with the prior literature [12,96]. Five interviewees emphasised that policies aimed at protecting existing energy-intensive industries (e.g. via exemptions from renewables surcharges) also was a key aspect of how the German energy transition could be seen as entailing industrial policy measures. A second broad perspective covering eight interviewees was that the German Energiewende policy is first and foremost energy policy although may have “industrial policy effects” (DE15, Trade Union). Within this second group, a range of factors were discussed. For one interviewee, there is “no industrial policy in the energy sector” (DE8, Industry Association). Another pointed to a lack of industrial policy in the case of the difficulties experienced by solar power with competition from China and contrasted Germany’s approach to solar with China’s state-led and subsidy-led approach (DE7, Research). Another interviewee, recognising the controversial nature of the term, emphasised that the Energiewende set “framework conditions” to enable competition and investment rather than being industrial policy (DE12, Ministry). So, while Germany is seen as a country where the state has played a key role in influencing the directionality of industry and the economy [45], within Germany there seems to be reluctance to acknowledge this as industrial policy, highlighting that perspectives on the role of industrial policy in German energy are complex.

Pertaining to *industrial visions* in Germany’s energy transition seven interviewees highlighted the importance of a long-term vision to transition away from a centralised energy system predominantly based on coal and nuclear towards a more decentralised, low-carbon renewable energy system, a vision rooted in societal movements in the 1980 s criticism of nuclear power and advocacy for renewable alternatives. This vision is encapsulated in the Energiewende and seen as providing guidance for industry. However, the vision does not explicitly include a green industrial policy component but rather more generally foregrounds industry competitiveness as one of the main policy objectives. One interviewee pointed out that “the writing has been on the wall for so long” with regards to the shift to renewables and energy efficiency (DE5,

Think Tank), whereas another highlighted that “*industry has fully accepted the Energiewende, participated in it, picked it up*” (DE13, Ministry). Thus, there was evidence that interviewees perceived that there was coherence with regards to the direction of the energy sector, arguably befitting of industrial policy. Indeed, long-term visions are an important part of ‘mission oriented’ industrial policy and Mazzucato refers to the German energy transition as a ‘model’ example” ([97]: 14). However, while it seems that a long-term vision of the Energiewende and the associated multi-actor consensus was vital in driving the initial stages of industrial shifts towards a green economy, in terms of more recent developments, four interviewees identified a lack of strategic vision around the next stages of the energy transition. They remarked that, in relation to important decisions on future trajectories and industrial policy decisions around key issues such as the roll out of electric vehicles, the current government is “*fearful of visions... and are extremely fearful, especially in Germany, of introducing some sort of modern planned economy*” (DE3, Research).

The **industrial policy instruments** identified by interviewees ranged from instruments aimed at protecting existing industries to those promoting new technological trajectories. Nine interviewees highlighted the role that the surcharge exemption of the Renewable Energy Sources Act (EEG)¹ has played in protecting existing energy intensive industries, such as the steel and chemical industry, from the additional costs created by the support for renewable energy through the Feed-in-Tariff system. As stated by one interviewee “*...you have to see that the competitive conditions fit somehow and the burden does not become too big there, because the logic from an environmental perspective is: the material is needed, not only for the Energiewende, but also for other sectors*” (DE12, Ministry). Export promotion was identified by five interviewees as an important coordination instrument utilised to promote new green technologies. The importance of public R&D support as an aspect of industrial policy was discussed by five interviewees. For example, one interviewee commented that “*you want to nurture perhaps a technological innovation system. If you look at it from that point of view you see that there are numerous policy instruments... [including]...the classical R&D support*” (DE11, Research). In addition to measures to protect existing industries, export promotion, and R&D support, the literature identifies other industrial policy instruments utilized in Germany, but that were generally not addressed by the interviewees in the context of industrial policy. These include loan programmes for solar and wind, sector specific innovation cluster support programmes and the Renewable Energy Sources Act (EEG) with its FiTs [83], although particularly the latter raise the point of the difficulty in delineating between what is energy policy and what is industrial policy.

In relation to **industrial policy governance** the literature on German industrial policy stresses the importance of embedded institutional structures of finance, employer associations, universities and research centres coordinating at the regional level for Germany’s industrial policy [33]. However, these institutional characteristics which are identified as key in understanding Germany’s approach to industrial policy [6,33] were not discussed extensively by interviewees. Only two interviewees spoke about the importance of the regional level for industrial and structural policies being introduced for particular regions in the context of the Energiewende. Offshore wind was mentioned as a prime example, with regional attempts to promote infrastructure and industrial clusters. In this context, one interviewee reckoned that in order to facilitate structural change you cannot rely on the market alone but “*you need exactly this kind of industrial and structural policy*” (DE15, Union).

Finally, regarding **employment concerns** eight interviewees discussed the role of jobs and trade unions for the German low-carbon energy transition. Five interviewees perceived the importance of the creation of new jobs through the building up of a renewables industry as

an important aspect of the German energy transition. Five interviewees also mentioned the importance of securing jobs in the face of the energy transition in relation to coal and other industries. Within this discussion, the differing positions of trade unions were emphasised as an important dimension. This is reflected by the difference between IG Metall as a union firmly on board with the Energiewende and other unions, such as those representing lignite mining, coal power production and energy intensive industries, who take a more critical stance (noted by four interviewees). In Germany, trade unions are an important factor in how industrial policy operates, where long-established societal agreements including the Works Constitution Act and the Collective Bargaining Law enable “*work councils to get involved in firms’ strategic decisions regarding the introduction of new technologies or organisations*” ([76]: 25), which contrasts with the degree of engagement unions have elsewhere. The literature further discusses a number of embedded policies in place around sustaining skills in manufacturing through public expenditure [50], but while considered key to German industrial policy these were not mentioned by interviewees.

4.2.2. UK

Regarding the **role** of industrial policy, there was general consensus that industrial policy had not played a role in UK low carbon energy transitions (mentioned by seven interviewees). One interviewee pinpointed the role of the UK treasury and that it had “*...constantly set its face against the notion that we should have regional or industrial strategy*” (UK 8, Think Tank). Five interviewees identified the lack of industrial policy as symptomatic of the liberalised approach to energy policy which had dominated with the emphasis on ‘not picking winners’. A Civil Servant noted that “*the current policy in the last 20 years has always been to use markets to drive the existing [energy] system...the government’s approach is to do much the same*” (UK 11, Ministry). Three interviewees noted that support for many renewables had been short lived with policies implemented in 2010 radically reduced in 2015 causing deep uncertainty for the renewables industry. However, offshore wind is an area where industrial policy has been present, while only one interviewee alluded to this. Despite originally being the most expensive technology, offshore wind was supported strategically since the mid-2000s. Along with government subsidies, support for offshore wind has included measures to encourage manufacturing of blades for offshore wind turbines to boost ‘green jobs’ [98], plans for boosting skills in an offshore wind industrial strategy [99], and more recently, more interventionist policies to implement ‘local content requirements’ [100]. Additionally, since 2007, the UK Government has strongly supported the construction of new nuclear power [101] ostensibly as part of a low-carbon strategy but with a clear priority around ‘maintaining the nuclear supply chain’ and protecting UK nuclear jobs and building up British nuclear skills [102-104].

One of the most unanimous points that stood out was agreement amongst eight interviewees of a lack of or unclear **industrial vision** in terms of long-term planning around the what industries should be prioritised for low carbon transitions with an emphasis on ‘not picking winners’. An interviewee remarked that “*I think there’s a lack of vision, and a lack of understanding of how everything fits together*” (UK8, Utility). Another interviewee specified that there was a lack of vision in relation to renewables, and the UK system remained based around a ‘centralised’ vision of energy production, where “*[o]ur electricity policy is essentially dominated by the need to perceive these, by the policy makers, to basically base our electricity system around a relatively small number of relatively large generating sets, which hasn’t changed since the ‘50 s*” (UK9, Think Tank). Despite the UK having one of the first legally binding climate change targets in the world with the Climate Change Act [105], institutional problems of short termism and a ‘stop start’ approach to policy has been noted in the literature [106]. This is exemplified by the sudden changes in 2015 to Feed-in-Tariff’s and other measures, which have had the effect of reducing investment in UK renewables by half by 2017 [107].

¹ As part of the EEG mechanism established in 2000, energy-intensive industries were exempted from paying the full surcharge to promote renewables.

In relation to **industrial policy instruments**, the interviewees did not mention the various measures taken around offshore wind or nuclear, and the Feed-in-Tariff schemes established in 2010 were not discussed in the context of industrial policy. Where four interviewees did see more proactivity in terms of industrial policy was in R&D and innovation activities. While it was noted that UK R&D support had fallen to very low levels in the 2000 s, in the last several years, “*there has been a succession of institutes set up*”, including the ‘energy catapult’ (UK 1, Research).

Relating to **industrial policy governance**, seven interviewees highlighted that UK governance was centralised and there was a lack of control at the regional level. One interviewee stated that “*in many other European countries there is actually a lot of activity at the regional level... Treasury governance on public finance, which gutted local authority, has meant you’ve taken out a whole layer of experimentation, innovation, development that’s available in other European countries*” (UK9, Think Tank). During the first decade of the 21st century, the New Labour Government sought to develop a regional industrial strategy. One interviewee remarked that “*there were institutional frameworks being created under Labour...which were about, really, creating a low-carbon industrial strategy*” where “*prominence were given to particular regions*” and “*strong, well-funded institutions*” (UK6, NGO)². However, in 2010, “*these were scrapped*” (UK6, NGO) when the Conservative Party came to power. The same interviewee did point to one lasting success story that survived this disruption, however: the Siemens turbine blade factory built on the Humber Side involving local stakeholders in planning and attracting Siemens to invest in the region. The centralised nature of UK governance is recognised in the literature, and different experiments aimed at enhancing regional powers over the past few decades, removed when a new party comes to power, seem to be a trend [108].

Most interviewees did not have much to say regarding **employment concerns**. However, a union member specialised in the area of low-carbon policy pointed out the significant difference between the UK and other European countries in terms of union engagement: in terms of unions being consulted with regards to energy policy decision making and industrial implications “*there isn’t very much... I mean, there is ad hoc stuff that goes on between government and unions. There is routine contact between government and industry, there is patchy stuff*” (UK7, Trade Union). This perspective is backed up by analysis comparing the ‘varieties of capitalism’ of different countries and the different roles afforded to unions in the decision making process [109,110]. In a review of union engagement across Europe the ETUC notes that the UK is a country where unions reported that they were often not involved in discussions on decarbonisation strategies³.

4.2.3. Denmark

Eight interviewees perceived that industrial policy had played a role in stimulating Danish low-carbon energy transition. One interviewee said that a focus early on was on creating the “*industrial base*” around wind energy, which “*created a strong industry*” (DK 20, Utility). Four interviewees acknowledged the particular role of politicians in directing strategic decisions within industry, particularly the Environment Minister Svend Auken in the 1990s. Politicians were pivotal in kick-starting the Danish Offshore wind industry where companies like Elsam and

² This was the Regional Development Agencies (RDAs) where the plan was to have different regions focussed on areas of industrial expertise for the low-carbon economy. For example, while the West Midlands were to lead on electric vehicles, the North East was to be focussed on offshore wind. Regional Development Agencies (RDAs) were abolished by the incoming Conservative Party as part of the ‘Localism Agenda’.

³ “In some Member States, TUs are still not consulted on climate & energy policy issues. Trade union representatives from the United Kingdom, Greece and Malta have, for example, indicated that they have not been involved in discussions related to their national long-term decarbonisation strategies.” ([14]: 14).

Energie 2, whose assets were mainly fossil fuel plants, were forced to change their industrial trajectory: “*it was not the companies who wanted to do it. It was an obligation from governments who forced them to do it, and then they had to figure out how to handle it of course*” (DK 1, Utility).

Eight interviewees mentioned the importance of the Danish Green **industrial vision** emerging from the anti-nuclear movement and the formation of the ‘Alternative Energy Plan’ which was important in setting the agenda of what the low-carbon industrial trajectory would follow: “*in the ‘70s and until 1985, where there was a decision in parliament not to have nuclear power, until then it was still open for what kind of path we should take. But, once a decision was taken in 1985...At that point in time it was clear we would be doing something else*” (DK 11, Ministry). Specifically, in relation to the offshore wind industry, four interviewees mentioned that particular politicians had ambitions about the potential for the creation of an industry and were influential in pushing this vision: “*it was decided sometime in the 1990s to try to go for offshore wind*” (DK1, Utility). The long-term nature of Danish political decisions related to green policy is quite remarkable, where “the successful take off of the Danish wind power industry since the mid-1980s was the result of the Government’s consistent support of and investment in wind power technology since the 1970 s” representing a “long-term vision and consistent policy framework”[111] .

A number of **industrial policy instruments** were recognised by the interviewees as being part of what could be considered as an industrial policy approach to low-carbon energy transitions. This includes subsidy schemes to expand district heating (DK2, Research), early taxes introduced on fossil fuels (DK 11, Ministry), grants for manufacturers of turbines in the early years (DK 17, Industry Association), and subsidies for offshore wind facilities and long-term R&D including test stations for wind developments (3 interviewees). According to the literature, the key motivation behind these instruments was “to build a globally competitive hub for creating innovative wind energy technology and highly paid jobs.” ([112]: 29).

Regarding **industrial policy governance**, the main theme was the governance changes which had occurred during the last decade or so. Since 2007, changes have been made to the regions in Denmark, transforming 11 regions into five, with the perception being that more power was shifted to the state level. The regions have no tax raising powers themselves and are funded by the state and municipalities. As a result of these changes, “[t]he regions do not have a very strong role in energy” (DK8, Ministry). Further, the ‘total planning’ system changed in which regions previously played a bigger role: “*[w]hen there came a new [liberal/right-wing] government...they didn’t want this planning system because they saw that it meant...a national district plan, socialistic planning system. They destroyed it totally*” (DK 8, Ministry). This contrasts with the historical role for regions in heat policy: “*They had a role in the heat planning business before, but otherwise, they have not really had a very big role in energy. It’s been mostly on the municipal level. But, I regard it as something that is missing*” (DK 2, Research). From the interviewees responses, it seems that the role of regions in industrial policy and energy is limited while municipalities have a key role in energy, yet it was not clear what bearing municipalities have on industrial policy.

Seven interviewees brought forward issues linking to **employment concerns**. The issue of the provision of jobs through renewable energy was a key part of Denmark’s post 1970 s industrial policy [113]. The role of jobs had a positive impact on support for the overall energy transition where “*wind turbines were developed by local manufacturers and created a lot of jobs so there was quite a drive towards wind power in the local communities*” (DK 17, Industry Association). Sustaining manufacturing and skills was therefore a key priority. As one interviewee outlined, “*we had a good argument. Especially [that] the windmill industry is a job for metal-workers...we also produce it in what you call the outskirts of the country.*” (DK 19, Politician). With the drive to shift Danish energy companies away from fossil fuels, there is also evidence of attention towards enabling workers in fossil fuel industries to maintain employment. One interviewee noted that, in the period in which DONG decided to

transform into a green utility company, they made a large effort, supported by the Ministry and the trade unions, to transfer highly skilled engineers related to fossil fuels to a new part of the company. However, for some jobs this was not possible and these skilled workers were transferred to other energy projects around the world: “*this was the way we eventually made the transition work so there was not too much resistance*” (DK 1, Utility). The strong role of unions and Danish commitments to just transitions as part of a clean energy strategy is something that is strongly noted by international observers and trade unions in other countries [114,115]. Five interviewees highlighted that early involvement of trade unions in discussions around jobs in wind energy.

4.3. Industrial policy as enabler or barrier of low-carbon energy transitions

In this third results section we portray our findings regarding whether certain elements of industrial policy, or a perceived lack of industrial policy, have acted as an enabler or barrier to low-carbon energy transitions.

4.3.1. Industrial policy as an enabler of low-carbon energy transitions

In Denmark and Germany, there was evidence from interviewees that industrial policy had played an enabling role in low-carbon energy transitions. Four out of 15 German interviewees expressed that industrial policy was an enabler of the initial energy transformation. Additionally, there was a recognition that while there may not have been an overt industrial policy angle to the Energiewende, there were “*industrial policy effects*” (DE13, Trade Union), such as job creation. In contrast, Danish interviewees broadly recognised that prioritisation around job creation had played an enabling role in low-carbon transitions in Denmark, including the key political role of the government and trade unions. It was emphasised by interviewees that not only did this create an industrial base that could construct a low-carbon energy industry, but this ensured a societal consensus around low-carbon transitions.

Despite the UK’s rapid growth in renewables capacity in recent years, industrial policy was not regarded as an enabling factor for this low-carbon energy transition. Most interviewees highlighted a past lack of industrial policy. At the same time, four interviewees pointed towards the rapid reversal in UK policy regarding policy support measures for renewables and energy efficiency in 2015 to highlight a lack of long-term industrial vision which created uncertainty in terms of investment decisions.

4.3.2. Industrial policy as a barrier to low-carbon energy transitions

In the literature there is much discussion around the importance of industrial policy to accelerate low-carbon transitions [27,28,65]. However, industrial policies can also relate to protective measures for incumbent industries.

In the *German* case, a key theme that emerged related to the balance between policy instruments designed to protect incumbents from the adverse effects of the transition to renewable energies, such as increased costs, and instruments designed to support new green industries. One interviewee pointed out these are the “*two sides*” of industrial policy (DE5, Think Tank). Seven interviewees in Germany alluded to the pace of the German energy transition being slowed down due to industrial policy concerns. That is, it was argued that resistance by industrial trade associations, trade unions, and particular sectors based around arguments for the protection of German industry and jobs potentially caused a blockage to a more accelerated transition, for example through

exemptions from the EEG surcharge. As one interviewee argued: “*There are going to be winners and losers. The losers – the steel industry, the chemical industry, the nonferrous industry, to name a few examples – are politically very strong*”, leading to “*...a giant discrepancy between the stated political aims, the noble pronouncements and the measures taken.*” (DE 2, Government Ministry).

For the *UK*, the previous lack of industrial policy was identified as a barrier to more accelerated deployment of renewable energy. Also, the lack of industrial strategy was associated as an important dimension in the ‘lack of vision’ around a different energy paradigm, with a constant chopping and changing of policy direction creating uncertainty. Additionally, in terms of the recent shift to an overt ‘industrial strategy’, the interviewees noted that the industrial strategy appears to be more about lowering costs for existing industries rather than promoting new technological trajectories.

In terms of barriers, four Danish interviewees raised concerns that the increasing strategic importance of the wind industry to *Denmark* and the strong levels of state control in facilitating this industrial expansion, has centralised production into the hands of a few large companies. The industrial expansion and improvements in production methods assisted by the State through the provision of test fields and R&D has seen the traditional local production and local ownership models challenged, with increasing conflict around siting and financial remunerations from wind power production. For some, the increased steering and involvement of the state in the wind industry of Denmark represents a centralising process challenging some of the original grassroots and decentralised approaches that motivated the Danish energy transition originally. This may not have a bearing on CO₂ emission reductions but rather may challenge broader values entailed in Danish energy transitions.

5. Discussion and conclusions

In this section we discuss the perceived role of industrial policy in low-carbon energy transitions and how this differed between the three countries (for an overview, see Table 1).

5.1. Implicit industrial policy in German energy transitions

We argue that German industrial policy in the context of the Energiewende can best be described as ‘implicit industrial policy’. We have chosen this notion because, while in the literature it is recognised that Germany has had an industrial policy [65] particularly with regards to its manufacturing sector [89], a theme that emerged in the interviews was that it is not often publicly named as being industrial policy and that the preferred terminology is ‘competitiveness’. Thus, Germany has pursued some form of industrial policy without it being named as such. In the literature, Germany’s industrial policy in general is characterised by its stakeholder financing system including national and regional investment banks and ‘patient capital’, the Diversified Quality Production (DQP) system and wage bargaining systems, the key role of the ‘Mittelstand’, a publicly-subsidised vocational training system for skills, dense-inter corporate networks, and the role of the Fraunhofer Society [50,91,116,117]. However, such factors were not mentioned by our interviewees, suggesting a level of embeddedness whereby industrial trajectories in Germany are guided strongly by institutional conditions in keeping with notions of Germany as a ‘coordinated economy’ [118].

This form of embedded and implicit industrial policy may also point towards understanding the challenges of accelerating structural change

towards low-carbon trajectories. An indirect effect of phasing out coal on energy intensive industries such as steel and aluminium may be an initial increase in electricity prices due to the merit order effect. This might be one of the reasons why in the context of coal phase out discussions, these powerful industries and unions sometimes argue that phasing out coal could threaten Germany's international competitiveness. Also, unions in the coal sector itself, although now having a relatively small membership compared to other sectors, also have a significant role in particular regions in Germany regarding the speed of the coal phase out [71,119]. Therefore, Germany has agreed a rather slow coal phase out entailing evolving structural and regional policies to manage job losses and broader economic impacts [120]. The strong automotive sector is also likely to be a key site where the speed of the next phase of Germany's energy transition [72] will be tested.

5.2. Hidden to overt industrial policy in UK energy transitions

Since the 1980s the UK had relinquished an active industrial policy in favour of market-oriented 'competitiveness' drives [121]. Additionally, the UK's political system which is very centralised has been a barrier to regional industrial policy, and effort in introducing regional industrial policy under Labour largely failed. In addition, unlike in Germany or Denmark trade unions have often been excluded from energy policy decision making in the UK [109]. Therefore, it may not be surprising that the majority of UK interviewees did not perceive industrial policy playing a role within the low-carbon energy transition in the UK. Yet, it does seem that industrial policy concerns were influencing government support for particular technologies above others. From an early stage, despite being more expensive than other low-carbon options, offshore wind was prioritised by the government with an emphasis on building a UK supply chain and with strong policy support and coordination by Government [122].

This has included establishing 'local content requirements' to increase the share of British companies in the offshore supply chain. In addition, from 2006 onwards, an emphasis on supporting the development of British nuclear skills and capabilities through a new civil nuclear programme has been pursued by successive governments. This emphasis on nuclear has intensified in recent years with an intense prioritisation around sustaining the UK nuclear industrial base [103,104,123]. Given that at the same time support has been significantly reduced for other low-carbon technologies that are shown by the government's own figures to be more cost-effective than nuclear and offshore wind [124,125], it can be concluded that the UK government has to a certain extent, sought to pick winners. Yet, this would not be expressed by the government because of overarching commitments to liberalisation and 'not picking winners' [126]. Hence, we refer to this as hidden industrial policy. More recently however, the UK changed course, seeing the emergence of a much more overt 'industrial strategy', responding to the decline in UK manufacturing, low productivity levels, and significant regional inequalities, based around efforts to 'rebalance' the UK economy including a clean growth strategy, increased R&D spend, and 'sector deals' which are evolving at the time of writing [127,128].

5.3. Direct industrial policy in Danish energy transitions

The Danish energy transition is synonymous with the notions of a bottom-up transformation because of the vital role played by social movements, citizens, and local manufacturers in the 1970s and 1980s in changing the trajectory of the Danish energy system [129]. Perhaps

less well known, is the crucial role played by direct intervention by visionary politicians to influence industrial trajectories which emerged as a key theme in our interviews. This included 'forcing' companies to transfer more quickly to wind energy production in the 1990s through striking deals, alongside long-term and stable market intervention to promote wind turbine manufacturer and production. The role of the Danish state was therefore crucial. However, again in contrast to the UK and a lesser extent Germany, this may relate to political-economic factors which enabled politicians to take a more interventionist stance, given that many utilities were publicly owned in Denmark at the time and there was broad societal support for such a transition [130]. In contrast to the UK, trade unions play a central role in Danish political life, where two thirds of workers are in trade unions and the Danish case is often held as an example of a just transition – in simultaneously protecting and creating new secure jobs while undertaking a green transition. The latter stages of industrial policy were associated by some interviewees as contributing to a perceived 're-centralisation' of Danish energy policy with priorities set around supporting the offshore wind industry and larger infrastructure which may contrast with the more localised imaginaries that were influential in the initial stages of the Danish energy transition.

In our approach, we focused on perceptions that key energy sector stakeholders had on the connection of industrial policy and energy transitions. It, thus, did not conduct a thorough top-down analysis of policy mixes in each country. Structured policy mapping exercises and the development of policy mixes pertaining to the field of industrial policy would be an interesting area of further research, and one requiring a more detailed identification of boundaries and overlaps between the industrial policy domain and other policy domains. This is likely to become an increasingly relevant avenue of research as industrial policy takes centre stage in the context of Green New Deal plans and economic recovery from the coronavirus pandemic.

5.4. Concluding Remarks: The importance of studying industrial policy in low-carbon energy transitions

This paper has revealed different styles of industrial policy in energy transitions, outlining differences between perceptions of key energy sector actors regarding the role of industrial policy, and what is understood in key literatures and policy. In Germany, an unease at the use of the term 'industrial policy' due to its ideological implications was clear, despite the German case often being heralded as an example of green industrial policy driving the energy transition. In the UK, industrial policy was not recognised by interviewees as playing a role with broader commitments to liberalisation and 'not picking winners' cited. Yet, interventionist policies around offshore wind and prioritisations around nuclear employment and capabilities highlight that industrial policy related factors have been important in driving long-term policy for those particular technologies. Meanwhile, Denmark exhibited a more open approach to industrial policy where decisive political intervention was accepted as playing a key role in shifting the direction of the energy industry towards a low-carbon trajectory. Thus, rather than discrete and identifiable policy instruments, industrial policy is clearly influenced by the very different political cultures present in these countries. Thus, applying lessons across countries of what type of industrial policy 'works' may be challenging because industrial policy may more often than not, be about institutionally embedded governance styles rather than any overtly stated policy.

We have outlined, using four elements of industrial policy to guide

our analysis (industrial visions, industrial policy instruments, industrial policy governance and employment concerns), the different ways in which industrial policy has been pursued in relation to energy in the three countries. As well as identifying differing industrial policy styles in different countries, the interviewees identified aspects of industrial policy as both enabling but at times hindering low-carbon energy transitions. This suggests that rather than being a panacea for accelerating low-carbon energy transitions, diverse consequences may result from the resurgence of industrial policy that call for a closer examination of the particular mix of policies in a given industrial policy context. The number of decisions already made by governments to phase-out old technologies (and industries) has increased the importance of employment concerns as part of emerging just transitions frameworks.

A key issue relates to what one interviewee identified as the ‘two sides’ of the industrial policy coin in terms of the balance between policies aimed at protecting existing industries and jobs, and policies aimed at promoting newer technological trajectories and job opportunities. This chimes with work in sustainability transitions which is attentive to the creative and destructive elements in policy mixes and how such a balance is constituted [131]. With an enhanced role of the state, there is well-known risk of ‘regulatory capture’ in relation to industrial policy where vested interests gain enhanced support from the state while newer industries may struggle to receive similar levels of support [132]. Examples of this were suggested by interviewees and in the literature, including the German car industry, coal industry, and the nuclear sector in the UK. Therefore, a focus on horizontal coordination measures and including a diversity of industrial actors in decision-making around industrial policy to avoid regulatory capture is an important concern as industrial policy gains traction in the context of Green New Deal discussions in Europe and beyond.

Another important difference amongst the cases is that there has been more disruption of existing business models, energy companies, and dominant grid design paradigms in Germany than the UK, with new actors and forms of ownership (such as energy cooperatives) having emerged in Germany, reducing the market share of incumbents, while in the UK major utilities still dominate the energy market and the role of new actors like cooperatives remains marginal [133,134]. Similarly, in Denmark, significant changes in ownership in the energy system occurred that could be considered ‘disruptive’ of ‘established networks of power’ [135]. However, focussing on disruption more broadly, it could be argued that industrial policy decisions in Denmark included efforts to sustain jobs, for example by actively retaining skills and capacities related to offshore oil activities within the emerging wind industry, lessened the disruptive effects of transitions. Similarly, Germany’s much criticised agreements for coal phase out by 2038, negotiated with companies, unions, regions and other stakeholders can be seen as a policy intervention to manage structural decline [136,137]. This may contrast with the adversarial approach taken with coal mining closure in the UK which continues to have significant disruptions in terms of poverty rates and a range of social indicators in former coal mining regions in the UK in the absence of significant industrial policy interventions [138]. Thus, it seems apparent that industrial policy measures have in some cases stimulated systemic disruption but, have also been drawn upon to mitigate against other dimensions of disruption in Germany and Denmark.

Another point of relevance to sustainability transitions is how the directionality of energy transitions may be influenced by industrial policy concerns. This relates to industrial variety and how the directionality of industrial policy is influenced by existing industrial

capabilities. For example, while our interviewees did not discuss biomass with regards to industrial policy in Denmark, it was significantly supported since the 1980 s and built on existing agricultural capabilities to build a domestic industry [139]. Similarly, the Danish offshore wind industry built on existing capabilities and infrastructures around offshore oil and gas [140]. This has been observed elsewhere, in terms of ‘technological overlaps’ between fossil fuel industries and new renewable industries [26]. Solar, on the other hand, was a technology that did not initially receive significant support from the Danish government and was a technology where existing industrial capabilities were perhaps not as pronounced. However, the UK also had significant capacities in the offshore oil and gas sector which may have also influenced its prioritisation of offshore wind, however so the UK did not manage to build significant UK content with regards to an offshore wind manufacturing industry [141,142]. Further research in sustainability transitions could explore how technological overlaps influence directionality in transitions, which raises significant issues regarding definitions and relations between ‘niche’ and ‘regime’ developments [21]. While our discussions have focussed more on the aspect of stimulating the creation of new industries as a form of green industrial policy, industrial transformation of existing industries will also form a key component of green industrial policy especially in relation to discussions of ‘deep decarbonisation’ of sectors such as steel [143].

Despite its elusiveness, the industrial policy lens is also a fruitful one through which to view sustainability transitions. It directs attention towards areas and issues including manufacturing, skills programmes and training, job retention and creation and under-researched key actors in transitions such as trade unions. Simultaneously, calls for enhanced green industrial policy to accelerate energy transitions through industrial policy can benefit greatly from work done in sustainability transitions on the balancing act between policies aimed at the niche and regime, the role of institutional rules, and key actors and networks in shaping the ‘balance’ between different types of industrial policy, and the political struggles inherent in constituting how that balance is weighted. Since our analysis rests on data collected in 2016/17 and energy transitions remain a highly dynamic field, future research should trace changes in perceptions of industrial policy in energy transitions in light of greater attention to Green New Deals and covid-19 recovery packages.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This research was funded by the Strategic Research Council of the Academy of Finland (grant numbers 293405, 314325).

Appendix A

[Table A1](#)

[Table A2](#)

[Table A3](#)

Table A1
Role of industrial policy and its elements in Germany.

Elements	Key points	Illustrative quotations (own translation)
Role of industrial policy in energy transition	* The Energiewende as encapsulating green industrial policy	“a very central [role] in deliberately building up industry” (DE11, Research)“The EEG has industrial policy effects but is not really an industrial policy instrument, but an energy-economic instrument” (DE15, Trade Union)
Industrial visions	* The Energiewende not being constituted by industrial policy * Long term vision and consensus around energy system change encapsulated in the Energiewende	“there has been a broad coalition...a strong consensus [...] about the nuclear phase-out, where you could say [...], that this is something collectively wanted. This is, I think, an important engine [...]” (DE15, Trade Union)“[...] there is rather some sort of muddling through and pragmatic solving of short-term problems rather than expose themselves and develop a rather long-term vision” (DE3, Think Tank).
Industrial policy instruments	* Perceived lack of strategic vision, but rather ‘muddling through’ in terms of evolving industrial policy * Protective measures for energy-intensive industries (including EEG surcharge exemptions foreseen in the Renewable Energy Sources Act) * Innovation policy to promote domestic technology development (including public R&D support in solar industry) * Export promotion extended to renewables	“this first element [of industrial policy], the reactive, can be seen for example in the exemptions energy-intensive industries have from the EEG levy, from electricity taxes, so that in the end they have comparable energy costs to other OECD countries, or developed countries, or their foreign competitors – this is, I believe, something that was intended right from the outset.” (DE5, Think Tank)“Public R&D funding is extremely important in order to make sure that technology development is really taking place in the country where you want to have it...it is absolutely a key element. And there is a PV story between 2002 and 2012 - it was a big success story which showed that it really worked: you had research results, you had educated people who came out of universities and who were needed building up the industry. It worked out very, very well.” (DE7, Research)“The ‘Export Initiative Strategy’ somehow merged with the ‘Mittelstand Global’...they are very bustling, do a lot of information tours, consult a lot of experts...there are a lot of activities, a lot of consultants are paid for it” (DE8, Industry Association)
Industrial policy governance	* Key role of regional industrial policies (e.g. stimulating offshore wind industry to mitigate job loss from ship-building) * Important role of regions in R&D programmes and experiments * (e.g. SINTEG programme)	“Projects motivated by industrial and structural policy [...] create synergy effects for these regions and thus organise the transition of job losses from ship construction towards new occupations [in offshore wind]” (DE15, Trade Union)“We have the SINTEG programme with its various sub-programmes for promoting a decentralised grid structure. In Baden-Württemberg itself we have a few programmes [...] concerned with energy storage units and such things. There are a range of initiatives.” (DE4, Utility)
Employment concerns	* Unions blocking low-carbon energy transition * Unions playing a progressive role in low-carbon energy transitions	“Right now, both the Unions and politicians are blocking everything related to [...] lignite...we will fail magnificently to meet our 2020 climate targets” (DE2, Ministry)“The IG Metall Union is a very progressive union which has realised opportunities coming from the disruptive transformation of the energy system” (DE7, Research)

Table A2
Industrial policy in the UK.

	Key point	Illustrative quotation
Role of industrial policy in energy transitions	Lack of industrial policy in UK energyMarket-oriented approach and economic liberalisation as barrier for renewables	“You had a kind of ad-hoc, the market will decide, which might be considered as industrial policy, I’m not sure. It’s not really a policy to just allow things to happen. I think as a result of that we do have a bit of a mismatch in terms of what energy we have.” (UK2, Politician)“So privatised industry hasn’t helped the cause for renewables either. Renewables are increasing but not as fast as they could have increased with a much more concerted effort. If we’d adopted the same enthusiasm and discipline and sense of direction and need to renewables as we did to post-war nuclear we wouldn’t be in a situation where we are today” (UK4, Ministry)
Industrial visions	A lack of vision around energy policy related to dominance of market-based approach	“There’s not been a strategic plan for what the infrastructure can look like, what the infrastructure should look like and it’s been a little bit ad-hoc, i.e. I don’t know what the government thinks that the energy system is going to look like in ten years’ time, I’m not entirely convinced they know what it’s going to look like in ten years’ time, and whilst I don’t think we can expect them to be absolutely spot on in their predictions I think a direction of travel would be helpful.” (UK2, Politician)
Industrial policy instruments	R&D and innovation policy	“They’ve started funding things that are potentially disruptive. They’ve started doing Smart Grid demonstration and started doing the whole portfolio of renewable technologies whether directly by government or agencies...now they have this Energy Systems Catapult which is the latest one” (UK1, Research)
Industrial policy governance	Scrapping of regional approach to industrial policy	“That [regional approach] was scrapped. So, there were institutional frameworks being created under Labour, which were about, really, creating a low-carbon industrial strategy to deliver. The Miliband structure gave pre-eminence to different regions, would lead on different things. So, the West Midlands was to lead on electric vehicles, Yorkshire and the Humber with carbon capture, the South West was going to be nuclear, the North East was going to be offshore wind.” (UK7, Trade Union)
Employment concerns	Lack of involvement of trade unions in energy policyLoss of key engineering skills	“I think the European model doesn’t apply in Britain, does it? I mean, the social partnership which is so prevalent in Germany and in Finland, where the natural thing for governments to do is to be seen to be in discussion with unions and with industry around the same table. I don’t want to over-romanticise this, but that is the norm. That is the Partnership Framework. It’s not normal in Britain.” (UK7, Trade Union)“...It’s not that CEBG were advocating and working to support renewables, they at least had engineers who understood the issues. Whereas today I should think that the numbers of, if you like, scientifically and engineering trained people still doing science and engineering in the privatised industry is very limited indeed.” (UK4, Ministry)

Table A3
Industrial policy in Denmark.

	Key point	Illustrative quotation
Role of industrial policy in energy transitions	Long term role of 'top down' push for wind in Denmark	"wind turbines were developed by local manufacturers and created a lot of jobs so there was quite a drive towards wind power in the local communities. There was also a top down push from the department and there has been a green majority more or less for many years in the department." (DK 17, Industry Association)
Industrial policy instruments	Early tax relief schemes for wind turbine manufacturersSubsidies for offshore wind development to create an industryLong-term R&D and provision of test stations	"I think the manufacturing sector has not been supported directly. They have been supported through the grants and subsidies to a point and they became the developers of the projects. Of course then that has enabled them to buy windmills and indirectly so we supported the manufacturers also" (DK 17, Industry Association). "The first offshore wind parks were again, heavily subsidised but I think that was more a subsidy to, you could say, the industry of wind turbine manufacturing. We have seen there was a potential that we could have a new export industry in Denmark." (DK 7 Industry Association) "Some new technologies have also been assisted through R&D... we have built some test stations...these test stations are quite important for manufacturers because if they have a new concept in the pipeline they can go there and test it and correct it also" (DK 17, Industry Association)
Industrial visions	Long-standing vision of energy transitionPolitical vision and action	"There's been this common strong story about green transition and transition to a low CO2 a society and that's a common task, a common goal that we have." (DK 3, Ministry) "And they were forced to do it...[move towards offshore wind in the 1990 s]...and they didn't like to do it, and at that time we were the first country- it was not the companies who wanted to do it. It was an obligation from governments who forced them to do it, and then they had to figure out how to handle it of course. And so this was a start of it, that it was a government pressure that started this" (DK 1, Utility)
Industrial policy governance	Change in the power of regions	"The thing that has changed...Then it was 11 or something and now we are 5 regions. The change is very specific that the regions have one major area, and that's the hospitals. Then we have a minor area" (DK 8, Ministry)
Employment concerns	Trade Unions playing a supportive role in transitions due to emphasis on job creation	"We convinced a lot of people in the unions back in the 90 s that green was not...disrupting the jobs, because you can create jobs...I think we had this discussion since at least the 80 s. It's also circular economy and all these things. It's a job creator." (DK 19, Politician).

References

- [1] L. Soete, From Industrial to Innovation Policy, *Journal of Industry, Competition and Trade* 7 (3-4) (2007) 273–284, <https://doi.org/10.1007/s10842-007-0019-5>.
- [2] E. Uyarra, J.M. Zabala-Iturriagoitia, K. Flanagan, E. Magro, Public procurement, innovation and industrial policy: Rationales, roles, capabilities and implementation, *Research Policy* 49 (1) (2020) 103844, <https://doi.org/10.1016/j.respol.2019.103844>.
- [3] T. Giordano, Integrating industrial policies with innovative infrastructure plans to accelerate a sustainability transition, *Environmental Innovation and Societal Transitions* 14 (2015) 186–188, <https://doi.org/10.1016/j.eist.2014.07.004>.
- [4] R.H. Wade, Return of industrial policy? *International Review of Applied Economics* 26 (2) (2012) 223–239, <https://doi.org/10.1080/02692171.2011.640312>.
- [5] D. Ciuriak, The return of industrial policy, *SSRN Electronic Journal* (2011) 1–74, <https://doi.org/10.2139/ssrn.1929564>.
- [6] J. Stiglitz, J. Yifu, C. Monga, Introduction: The Rejuvenation of Industrial Policy, in: J. Stiglitz, J. Yifu, C. Monga (Eds.), *Ind. Policy Revolut.*, New York: Palgrave Macmillan, 2013: pp. 1–18.
- [7] S. Lall, Reinventing industrial strategy: The role of government policy in building industrial competitiveness, 2003.
- [8] OECD Observer, Resurrecting industrial policy, *OECD Obs. Webpages*. 2012. http://oecdobserver.org/news/fullstory.php/aid/3814/Resurrecting_industrial_policy.html (accessed October 12, 2016).
- [9] D. Ciuriak, J. Curtis, *The resurgence of industrial policy and what it means for Canada, Policy Options* (2013).
- [10] T. Matsuo, T.S. Schmidt, Managing tradeoffs in green industrial policies: The role of renewable energy policy design, *World Development* 122 (2019) 11–26, <https://doi.org/10.1016/j.worlddev.2019.05.005>.
- [11] S. Hallegatte, A. Vogt-schilb, *Green Industrial Policies When and How*, Washington DC, 2013.
- [12] A. Pegels, W. Lütkenhorst, Is Germany's energy transition a case of successful green industrial policy? Contrasting wind and solar PV, *Energy Policy* 74 (2014) 522–534, <https://doi.org/10.1016/j.enpol.2014.06.031>.
- [13] A. Pegels (Ed.), *Green Industrial Policy in Emerging Countries*, Routledge, London, 2014.
- [14] J. Schwarzer, *Industrial Policy for a Green Economy*, Manitoba, 2013.
- [15] J. Grin, J. Rotmans, J. Schot, *Transitions to Sustainable Development*, Routledge, Abingdon, 2010.
- [16] J. Markard, R. Raven, B. Truffer, Sustainability transitions: An emerging field of research and its prospects, *Research Policy* 41 (6) (2012) 955–967, <https://doi.org/10.1016/j.respol.2012.02.013>.
- [17] G.P.J. Verbong, D.A. Loorbach, Introduction, in: G.P.J. Verbong, D.A. Loorbach (Eds.), *Gov. Energy Transit. Reality, Illusion or Necessity?*, Routledge, Oxon, 2013.
- [18] P. Johnstone, P. Newell, Sustainability transitions and the state, *Environmental Innovation and Societal Transitions* 27 (2018) 72–82, <https://doi.org/10.1016/j.eist.2017.10.006>.
- [19] X.-S. Yap, B. Truffer, Shaping selection environments for industrial catch-up and sustainability transitions: A systemic perspective on endogenizing windows of opportunity, *Research Policy* 48 (4) (2019) 1030–1047, <https://doi.org/10.1016/j.respol.2018.10.002>.
- [20] F. Kern, K.S. Rogge, M. Howlett, Policy mixes for sustainability transitions: New approaches and insights through bridging innovation and policy studies, *Research Policy* 48 (10) (2019) 103832, <https://doi.org/10.1016/j.respol.2019.103832>.
- [21] A.D. Andersen, M. Gulbrandsen, The innovation and industry dynamics of technology phase-out in sustainability transitions: Insights from diversifying petroleum technology suppliers in Norway, *Energy Research & Social Science* 64 (2020) 101447, <https://doi.org/10.1016/j.erss.2020.101447>.
- [22] R. Kemp, J. Schot, R. Hoogma, Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management, *Technology Analysis & Strategic Management* 10 (2) (1998) 175–198, <https://doi.org/10.1080/09537329808524310>.
- [23] F.W. Geels, Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study, *Research Policy* 31 (8-9) (2002) 1257–1274, [https://doi.org/10.1016/S0048-7333\(02\)00062-8](https://doi.org/10.1016/S0048-7333(02)00062-8).
- [24] B. Turnheim, F.W. Geels, Regime destabilisation as the flipside of energy transitions: Lessons from the history of the British coal industry (1913–1997), *Energy Policy* 50 (2012) 35–49, <https://doi.org/10.1016/j.enpol.2012.04.060>.
- [25] A.D. Andersen, M. Steen, T. Mäkitie, J. Hanson, T.M. Thune, B. Soppe, The role of inter-sectoral dynamics in sustainability transitions: A comment on the transitions research agenda, *Environmental Innovation and Societal Transitions* 34 (2020) 348–351, <https://doi.org/10.1016/j.eist.2019.11.009>.
- [26] T. Mäkitie, A.D. Andersen, J. Hanson, H.E. Normann, T.M. Thune, Established sectors expediting clean technology industries? The Norwegian oil and gas sector's influence on offshore wind power, *Journal of Cleaner Production* 177 (2018) 813–823, <https://doi.org/10.1016/j.jclepro.2017.12.209>.
- [27] D. Rodrik, Green industrial policy, *Oxford Review of Economic Policy* 30 (3) (2014) 469–491, <https://doi.org/10.1093/oxrep/gru025>.
- [28] T. Altenburg, C. Assmann, eds., *Green industrial policy: concept, policies, country experiences*, UN Environment; German Development Institute / Deutsches Institut für Entwicklungspolitik (DIE), Geneva, Bonn, 2017. <https://www.google.co.in/search?q=Trade+Barriers+Dim+Renewable+Energy%27s+Prospects&aq=Trade+Barriers+Dim+Renewable+Energy%27s+Prospects&aq=chrome..69i57j69i60.244j0j4&sourceid=chrome&ie=UTF-8#q=Green+industrial+policy&>

- [29] P. Johnstone, P. Kivimaa, Multiple dimensions of disruption, energy transitions and industrial policy, *Energy Research & Social Science* 37 (2018) 260–265, <https://doi.org/10.1016/j.erss.2017.10.027>.
- [30] A. Ocasio Cortez, *Green New Deal 16TH Congress 1st Session in the House of Representatives, House of Representatives, Washington DC, 2019*.
- [31] European Commission, *The European Green New Deal*, Eur. Com. Webpages, 2019. <https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1596443911913&uri=CELEX:52019DC0640#document2> (accessed September 23, 2020).
- [32] IPCC, *Global Warming of 1.5 °C an IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change*, Geneva, 2018. <http://www.ipcc.ch/report/sr15/>.
- [33] A. Andreoni, *Varieties of industrial policy: models, packages, and transformation cycles*, in: A. Noman, J. Stiglitz (Eds.), *Effic. Financ. Var. Ind. Policy*, Columbia University Press, Columbia, 2017.
- [34] Fraunhofer ISE, *Public Net Electricity Generation in Germany 2019: Share from Renewables Exceeds Fossil Fuels*, Fraunhofer ISE Webpages, 2020. <https://www.ise.fraunhofer.de/en/press-media/news/2019/Public-net-electricity-generation-in-germany-2019.html> (accessed June 1, 2020).
- [35] BEIS, *UK Energy Statistics, Department for Business, Energy & Industrial Strategy, The Stationery Office, Crown Copyright, London, 2020*.
- [36] State of Green, 2019: *The greenest year ever in Denmark*, State of Green Webpages, 2019. <https://stateofgreen.com/en/partners/state-of-green/news/2019-the-greenest-year-ever-in-denmark/> (accessed June 1, 2020).
- [37] C. Dhéret, M. Morosi, A. Frontini, A. Hedberg, R. Pardo, *Towards a New Industrial Policy for Europe*, Brussels, 2014. <https://dx.doi.org/ISSN1782-494X>.
- [38] E. Stoling, *Industrial Policy, Technology, and International Bargaining: Designing Nuclear Industries in Argentina and Brazil*, Stanford University Press, Stanford, 1996.
- [39] P. Bianchi, S. Labory, *From “old” industrial policies to “new” industrial development policies*, in: *Int. Handb. Ind. Policy*, Edward Elgar, Cheltenham, 2006, pp. 3–27.
- [40] B. Greenwald, J.E. Stiglitz, *Industrial policies, the creation of a learning society, and economic development*, in: J.E. Stiglitz, J. Yifu Lin (Eds.), *Ind. Policy Revolut. I Role Gov. Beyond Ideol.*, Palgrave Macmillan, London, 2013, pp. 43–71.
- [41] J. Yifu Lin, C. Monga, *Comparative advantage: the silver bullet of industrial policy*, in: *Ind. Policy Revolut.*, International Economic Association Series, 2013: pp. 19–38.
- [42] X. Vanden Bosch, *Industrial policy in the EU: A guide to an elusive Concept*, Brussels, 2014. www.academiairess.be.
- [43] J. Ossenbrink, S. Finnsson, C.R. Bening, V.H. Hoffmann, *Delineating policy mixes: Contrasting top-down and bottom-up approaches to the case of energy-storage policy in California*, *Research Policy* 48 (2019), <https://doi.org/10.1016/j.respol.2018.04.014>.
- [44] M. Mazzucato, *The Green Entrepreneurial State*, Brighton, 2015.
- [45] M. Mazzucato, M. Cimoli, G. Dosi, J.E. Stiglitz, M.A. Landesmann, M. Pianta, R. Walz, T. Page, *Which industrial policy does Europe need? Intereconomics* 50 (2015) 120–155, <https://doi.org/10.1007/s10272-015-0535-1>.
- [46] Franco Malerba, *Sectoral systems of innovation and production*, *Research Policy* 31 (2) (2002) 247–264, [https://doi.org/10.1016/S0048-7333\(01\)00139-1](https://doi.org/10.1016/S0048-7333(01)00139-1).
- [47] European Parliament, *General principles of EU industrial policy*, Eur. Parliam. Factsheet Webpages, 2016. http://www.europarl.europa.eu/atyourservice/en/displayFtu.html?ftuId=FTU_5.9.1.html (accessed October 12, 2016).
- [48] H. Karl, A. Möller, *Regional Industrial Policies in Germany*, Rome, 2003.
- [49] B. Hancké, S. Coulter, *The German manufacturing sector unpacked: Institutions, policies and future trajectories*, London, 2013. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/283889/ep13-german-manufacturing.pdf.
- [50] J. Kalman, M. Tiits, *Coordinated policies and cohesion policies: their relationship and impact on the Member States*, 2014. http://www.grincoh.eu/media/serie_7_institutional_convergence/grincoh_wp7.04_kalman_tiits.pdf.
- [51] C. Freeman, *Technology and Economic Performance: Lessons from Japan*, Pinter, London, 1987.
- [52] Stefan Četković, Aron Buzogány, *Varieties of capitalism and clean energy transitions in the European Union: When renewable energy hits different economic logics*, *Climate Policy* 16 (5) (2016) 642–657, <https://doi.org/10.1080/14693062.2015.1135778>.
- [53] Peter A. Hall, Daniel W. Gingerich, *Varieties of capitalism and institutional complementarities in the political economy: An empirical analysis*, *British Journal of Political Science* 39 (3) (2009) 449–482, <https://doi.org/10.1017/S0007123409000672>.
- [54] K. Warwick, *Industrial Policy: Emerging Issues and New Trends*, in: *Babbage Ind. Policy Netw. Lect. Ser.*, University of Cambridge, Cambridge, 2013. http://www.ifm.eng.cam.ac.uk/uploads/Research/Babbage/Ken_Warwick.pdf.
- [55] European Commission, *A New Industrial Strategy for Europe*, European Commission, Brussels, 2020. https://ec.europa.eu/info/sites/info/files/communication-eu-industrial-strategy-march-2020_en.pdf.
- [56] J. Valero, *Commission pledges action to ensure companies survive coronavirus*, Euractiv Webpages, 2020. <https://www.euractiv.com/section/economy-jobs/news/commission-pledges-action-to-ensure-companies-survive-coronavirus/> (accessed October 12, 2020).
- [57] M. Mazzucato, *Mission-Oriented Research and Innovation in the European Union: A problem-solving approach to fuel innovation-led growth*, European Commission, Brussels, 2018. <https://doi.org/10.2777/36546>.
- [58] T. Spencer, R. Pierfederici, O. Sartor, N. Berghmans, S. Samadi, M. Fishedick, K. Knoop, *State of the Low-Carbon Energy Union: Assessing the EU’s progress towards its 2030 and 2050 climate objectives a sectoral approach to deep decarbonisation in the EU progress needs strong reinforcement and scaling up*, Grenoble, 2016.
- [59] C. Böhlinger, N.J. Rivers, T.F. Rutherford, R. Wigle, *Green jobs and renewable electricity policies: Employment impacts of Ontario’s feed-in tariff*, *B.E. J. Econ. Anal. Policy*. 12 (2012), <https://doi.org/10.1515/1935-1682.3217>.
- [60] M.S. Cato, J. Essex, N. Bennett, R. Büttikofer, J. Blom, *Green industry in a post-industrial society*, *Green Eur. J.* 6 (2013).
- [61] W. McDowall, P. Ekins, *Green innovation: industrial policy for a low-carbon future*, London, 2014.
- [62] F. Creutzig, J. Christoph, P. Lehmann, E. Schmid, F. Von Blücher, C. Breyer, B. Fernandez, M. Jakob, B. Knopf, S. Lohrey, T. Susca, K. Wiegand, *Catching two European birds with one renewable stone: Mitigating climate change and Eurozone crisis by an energy transition, Renewable and Sustainable Energy Reviews* 38 (2014) 1015–1028, <https://doi.org/10.1016/j.rser.2014.07.028>.
- [63] M. Lockwood, *New Thinking: Financing (green) industrial strategy*, IGov Blog, 2016. <http://projects.exeter.ac.uk/igov/new-thinking-financing-green-industrial-strategy/> (accessed October 16, 2016).
- [64] W. Lütkenhorst, T. Altenburg, A. Pegels, G. Vidican, *Green Industrial Policy Managing transformation under Uncertainty*, Bonn, 2014.
- [65] Rob Raven, Bob Walrave, *Overcoming transformational failures through policy mixes in the dynamics of technological innovation systems*, *Technological Forecasting and Social Change* 153 (2020) 119297, <https://doi.org/10.1016/j.techfore.2018.05.008>.
- [66] Paula Kivimaa, Florian Kern, *Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions*, *Research Policy* 45 (1) (2016) 205–217, <https://doi.org/10.1016/j.respol.2015.09.008>.
- [67] P. Stegmaier, S. Kuhlmann, V. Visser, *The discontinuation of socio-technical systems as a governance problem*, in: S. Borras, J. Edler (Eds.), *Gov. Socio-Technical Syst. Explain. Chang.*, Edward Elgar, Cheltenham, 2014, pp. 111–131.
- [68] S. Jacobsson, V. Lauber, *The politics and policy of energy system transformation—explaining the German diffusion of renewable energy technology*, *Energy Policy* 34 (2006) 256–276, <https://doi.org/10.1016/j.enpol.2004.08.029>.
- [69] L. Prinz, A. Pegels, *The role of labour power in sustainability transitions: Insights from comparative political economy on Germany’s electricity transition*, *Energy Research & Social Science* 41 (2018) 210–219, <https://doi.org/10.1016/j.erss.2018.04.010>.
- [70] J. Markard, *The next phase of the energy transition and its implications for research and policy*, *Nature Energy*. (2018) 1–6, <https://doi.org/10.1038/s41560-018-0171-7>.
- [71] J. Schot, E.W. Steinmueller, *Three frames for innovation policy: R&D, systems of innovation and transformative change*, *Research Policy* (2018), <https://doi.org/10.1016/j.respol.2018.08.011>.
- [72] Karl Aiginger, Susanne Sieber, *The Matrix Approach to Industrial Policy*, *International Review of Applied Economics* 20 (5) (2006) 573–601, <https://doi.org/10.1080/02692170601005507>.
- [73] F. Dobbin, *Forging Industrial Policy: the United States, Britain, and France in the railway age*, Cambridge University Press, Cambridge, 1994.
- [74] H.-J. Chang, A. Andreoni, M.L. Kuan, *International industrial policy experiences and the lessons for the UK*, London, 2013. <http://eprints.soas.ac.uk/19244/1/ep4-international-industrial-policy-experiences.pdf>.
- [75] D. Bailey, A. Glasmeier, P.R. Tomlinson, P. Tyler, *Industrial policy: New technologies and transformative innovation policies? Cambridge Journal of Regions, Economy and Society* 12 (2019) 169–177, <https://doi.org/10.1093/cjres/rsz006>.
- [76] Neil Lee, *No city left behind? Place-based industrial policy after the recession*, *Local Economy* 25 (8) (2010) 607–611, <https://doi.org/10.1080/02690942.2010.533432>.
- [77] Tim Vorley, Jen Nelles, *Innovation policy as industrial policy: some lessons from Hamburg’s regional innovation system*, *Local Economy* 25 (8) (2010) 631–649, <https://doi.org/10.1080/02690942.2010.533422>.
- [78] A. Lijphart, *Patterns of Democracy: Government Forms and Performance in 36 Countries*, 2nd ed., Yale University Press, Yale, 2012.
- [79] D. Engel, D.M. Kammen, M. Wei, S. Patadia, C.S. Januario, *Green Jobs and the Clean Energy Economy*, Copenhagen Climate Council, Copenhagen, 2009.
- [80] UNEP, *Green Jobs: Towards decent work in a sustainable, low-carbon world*, United Nations Environment Programme, New York, 2008.
- [81] W. Lütkenhorst, A. Pegels, *Stable Policies – Turbulent Markets: The costs and benefits of promoting Solar PV and Wind Energy*, Geneva, 2014.
- [82] K. Aiginger, *Industrial Policy for a sustainable growth path*, Vienna, 2014. <https://www.oecd.org/eco/Industrial-Policy-for-a-sustainable-growth-path.pdf>.
- [83] R. Yin, *Case Study Research: Design and Methods*, 3rd ed., Sage, London, 2003.
- [84] John M Bryson, *What to do when stakeholders matter: stakeholder identification and analysis techniques*, *Public Management Review* 6 (1) (2004) 21–53, <https://doi.org/10.1080/14719030410001675722>.
- [85] Leon M. Hermans, Wil A.H. Thissen, *Actor analysis methods and their use for public policy analysts*, *European Journal of Operational Research* 196 (2) (2009) 808–818, <https://doi.org/10.1016/j.ejor.2008.03.040>.
- [86] R. Rhodes, *Energy: A Human History*, Simon & Schuster, London, 2018.
- [87] L. Elliot, *The UK could learn a lot from Germany’s long-term industrial strategy*, Guardian Online. (2016). <https://www.theguardian.com/global/2016/mar/30/the-uk-could-learn-a-lot-from-germanys-long-term-industrial-strategy>.

- [90] M.P.A. Craig, 'Treasury control' and the British environmental state: The political economy of green development strategy in UK Central Government, *New Political Economy* 25 (2020) 30–45, <https://doi.org/10.1080/13563467.2018.1526269>.
- [91] E. O'Sullivan, A. Andreoni, C. Lopez-Gomez, M. Gregory, What is new in the new industrial policy? A manufacturing systems perspective, *Oxford Review of Economic Policy* 29 (2) (2013) 432–462, <https://doi.org/10.1093/oxrep/grt027>.
- [92] C. Berry, Industrial policy change in the post-crisis British economy: Policy innovation in an incomplete institutional and ideational environment, *British Journal of Politics and International Relations* (2016) 830–847, <https://doi.org/10.1177/1369148116667650>.
- [93] BEIS, in: *Industrial Strategy: Building a Britain Fit for the Future*, Crown Copyright, London, 2017, <https://doi.org/10.1049/ir:19930092>.
- [94] O.K. Pedersen, Denmark's Negotiated Economy, Copenhagen, 2005.
- [95] J.L. Campbell, O. Pedersen, The varieties of capitalism and hybrid success Denmark in the global economy, *Comparative Political Studies* 40 (2007) 307–332.
- [96] R. Boeckle, M. Dua, D. Henriques, P. Simon, F. Tronci, *The German Wind Technology Cluster: Microeconomics of Competitiveness*, Cambridge MA, 2010.
- [97] M. Mazzucato, *Mission-Oriented innovation policy challenges and opportunities*, UCL Institute for Innovation and Public Purpose (2017) 1–41.
- [98] H. Mullholland, Ed Miliband announces boost for green jobs, *Guardian Online*. (2009), <https://www.theguardian.com/politics/2009/sep/16/ed-miliband-wind-turbines>.
- [99] HM Government, *Offshore Wind Industrial Strategy Business and Government Action*, London, 2013.
- [100] D. Weston, Next UK auction winners "will require" local content, *Wind Power Mag*. (2016). <http://www.windpoweroffshore.com/article/1383483/next-uk-auction-winners-will-require-local-content> (accessed July 12, 2016).
- [101] A. Stirling, P. Johnstone, A Global Picture of Industrial Interdependencies Between Civil and Military Nuclear Infrastructures Editorial Assistance, Brighton, 2018.
- [102] Oxford Economics, *The Economic Benefit of Improving the UK's Nuclear Supply Chain Capabilities*, Oxford Economics Institute, Oxford, 2013.
- [103] NAO, Hinkley Point C, National Audit Office, London, 2017. <https://www.nao.org.uk/wp-content/uploads/2017/06/Hinkley-Point-C.pdf>.
- [104] Nuclear Industry Council, *The Nuclear Sector Deal Nuclear Industry Council Proposals to Government for a Sector Deal*, Nuclear Industry Council, London, 2017.
- [105] HM Government., UK Climate Change Act, HM Gov. Webpages. (2008). <http://www.legislation.gov.uk/ukpga/2008/27/contents> (accessed July 12, 2017).
- [106] Mitchell, M. Lockwood, R. Hoggett, C. Kuzemko, *Governing for Innovation Without Disruption in Energy Systems*, in: BIEE Int. Conf., BIEE conference, Oxford, 2016: pp. 1–21.
- [107] House of Commons Environmental Audit Committee, *Green finance: mobilising investment in clean energy and sustainable development*, Crown Copyright, London, 2018. <https://publications.parliament.uk/pa/cm201719/cmselect/cmenvaud/617/61703.htm>.
- [108] Johnstone, The crisis at the centre of the United Kingdom: Exploring Scottish independence and democratically disruptive regions, 2017. <https://doi.org/10.4324/9781315679723>.
- [109] P. Hampton, *Workers and Trade Unions for Climate Solidarity: Tackling Climate Change in a Neoliberal World*, Routledge, London, 2015.
- [110] P. Hall, D. Solskice, *Varieties of Capitalism: The Institutional Foundations of Comparative Advantage*, Oxford University Press, Oxford, 2001.
- [111] UNESCAP, *Wind power takes flight in Denmark: Denmark's renewable energy policies*, Vienna, 2016.
- [112] R. Lema, J. Nordensvärd, F. Urban, W. Lütkenhorst, *Innovation Path in Wind Power - Insights from Denmark and Germany*, Deutsches Institut für Entwicklungspolitik gGmbH Tulpenfeld, Bonn, 2014. http://www.die-gdi.de/uploads/media/NEU_DP_17.2014.pdf%5Cnhttp://www.die-gdi.de/en/discussion-paper/article/innovation-paths-in-wind-power-insights-from-denmark-and-germany/.
- [113] J. Campbell, O. Pedersen, Comparative political studies Denmark in the global economy, *Comparative Political Studies* 40 (2007) 307–332, <https://doi.org/10.1177/0010414006286542>.
- [114] TUC, *Powering ahead: How UK industry can match Europe's environmental leaders*, London, 2016.
- [115] C.L. Ibsen, *Trade Unions in Denmark*, Friedrich-Ebert-Stiftung, Berlin, 2012.
- [116] C. Chlebna, *The Role of Institutions for the Path dependent Development of the Wind Energy Industry in Germany and Britain*, Oxford Brookes University, 2017. <https://doi.org/10.1146/annurev.nutr.23.011702.073307>.
- [117] S. Vitols, *German industrial policy: An overview*, *Industry and Innovation* 4 (1997) 15–36, <https://doi.org/10.1080/13662719700000002>.
- [118] P.A. Hall, D. Siskice (Eds.), *Varieties of Capitalism: The Institutional Foundations of Comparative Advantage*, Oxford Univ Press, Oxford, 2001.
- [119] S. Vögele, P. Kunz, D. Rübbecke, T. Stahlke, Transformation pathways of phasing out coal-fired power plants in Germany, *Energy, Sustainability and Society* 8 (2018), <https://doi.org/10.1186/s13705-018-0166-z>.
- [120] T. Buck, Germany set to phase out coal-fired power stations by 2038, *Financ. Times Online*. (2019). <https://www.ft.com/content/cfae297e-213c-11e9-8ce6-5db4543da632>.
- [121] C. Wren, The industrial policy of competitiveness: A review of recent developments in the UK, *Regional Studies* 35 (2001) 847–860, <https://doi.org/10.1080/00343400120090266>.
- [122] F. Kern, A. Smith, C. Shaw, R. Raven, B. Verhees, From laggard to leader: Explaining offshore wind developments in the UK, *Energy Policy*. 69 (2014) 635–646, <https://doi.org/10.1016/j.enpol.2014.02.031>.
- [123] HM Government, *The Nuclear Supply Chain Action Plan*, London, 2012.
- [124] J. Murray, UK energy policy reset - the reaction, *Bus. Green*. (2015). <http://www.businessgreen.com/bg/analysis/2435180/uk-energy-policy-reset-the-reaction> (accessed December 12, 2016).
- [125] P. Johnstone, A. Stirling, B. Sovacool, Policy mixes for incumbency: Exploring the destructive recreation of renewable energy, shale gas 'fracking', and nuclear power in the United Kingdom, *Energy Research & Social Science* 33 (2017) 147–162, <https://doi.org/10.1016/j.erss.2017.09.005>.
- [126] P. Pearson, J. Watson, *UK Energy Policy 1980-2010: A history and lessons to be learnt*, The Parliamentary Group for Energy Studies, London, 2012.
- [127] Jonathan Busch, Timothy J. Foxon, Peter G. Taylor, Designing industrial strategy for a low carbon transformation, *Environmental Innovation and Societal Transitions* 29 (2018) 114–125, <https://doi.org/10.1016/j.eist.2018.07.005>.
- [128] HM Government, *The Clean Growth Strategy: Leading the way to a low carbon future*, Department for Business Enterprise and Regulatory Reform, Crown Copyright, London, 2017. <https://www.gov.uk/government/>.
- [129] Thomas Bauwens, Boris Gotchev, Lars Holstenkamp, What drives the development of community energy in Europe? The case of wind power cooperatives, *Energy Research & Social Science* 13 (2016) 136–147, <https://doi.org/10.1016/j.erss.2015.12.016>.
- [130] K.M. Araújo, *Low Carbon Energy Transitions: Turning Points in National Policy and Innovation*, Oxford University Press, Oxford, 2017.
- [131] P. Kivimaa, F. Kern, Creative Destruction or Mere Niche Creation? Innovation policy mixes for sustainability transitions, *Research Policy* 02 (2015) 29, <https://doi.org/10.1016/j.respol.2015.09.008>.
- [132] J.J. Laffont, Industrial policy and politics, *International Journal of Industrial Organization* 14 (1996) 1–27, [https://doi.org/10.1016/0167-7187\(95\)00494-7](https://doi.org/10.1016/0167-7187(95)00494-7).
- [133] Phil Johnstone, Karoline S. Rogge, Paula Kivimaa, Chiara F. Fratini, Eva Primmer, Andy Stirling, Waves of disruption in clean energy transitions: Sociotechnical dimensions of system disruption in Germany and the United Kingdom, *Energy Research & Social Science* 59 (2020) 101287, <https://doi.org/10.1016/j.erss.2019.101287>.
- [134] C. Nolden, *Governing community energy-Feed-in tariffs and the development of community wind energy schemes in the United Kingdom and Germany*, *Energy Policy*. 63 (2013) 543–552. <https://doi.org/10.1016/j.enpol.2013.08.050>.
- [135] P. Karnøe, D.I. Vol, *How disruptive is wind power? A lesson from Denmark*, *Debating Innovation* 2 (2012) 72–77.
- [136] P.Y. Oei, H. Brauers, P. Herpich, Lessons from Germany's hard coal mining phase-out: policies and transition from 2015 to 2018, *Climate Policy* 20 (2020) (1950) 963–979, <https://doi.org/10.1080/14693062.2019.1688636>.
- [137] F. Schultz, German coal regions to be allocated €40 billion as part of coal phase-out plan, *Euractiv Webpages*. (2020). <https://www.euractiv.com/section/energy/news/german-coal-regions-to-be-allocated-e40-billion-as-part-of-coal-phase-out-plan/> (accessed September 24, 2020).
- [138] P. Johnstone, S. Hielscher, Phasing out coal, sustaining coal communities? Living with technological decline in sustainability pathways, *The Extractive Industries and Society* 4 (2017) 457–461, <https://doi.org/10.1016/j.exis.2017.06.002>.
- [139] N. Bensten, D. Nilsson, S. Larsen, I. Stupak, *Agricultural residues for energy in Sweden and Denmark – Differences and commonalities*, Paris, 2016. <https://www.ieabioenergy.com/wp-content/uploads/2018/01/EA-Bioenergy-Task-43-TR2016-05.pdf>.
- [140] A. Klein, *Winds of change: can big oil make the transition to offshore wind?*, World Bank Website. (2020). <https://blogs.worldbank.org/climatechange/winds-change-can-big-oil-make-transition-offshore-wind> (accessed September 24, 2020).
- [141] N.J. Smith, *Industrial policy : Lessons from the North Sea, Civilization Revolution 10* (2013). <http://www.civitas.org.uk/pdf/CivitasReview10-2v6.pdf>.
- [142] Labour Energy Forum, *Who owns the wind, owns the future*, Labour Energy Forum, 2017. <https://doi.org/10.1093/mnras/sts454>.
- [143] D. Kushnir, T. Hansen, V. Vogl, M. Ahman, *Adopting hydrogen direct reduction for the Swedish steel industry: A technological innovation system (TIS) study*, *Journal of Cleaner Production* 242 (2020), <https://doi.org/10.1016/j.jclepro.2019.118185>.