The whole systems energy injustice of four European low-carbon transitions

Article (Accepted Version)

Sovacool, Benjamin, Hook, Andrew, Martiskainen, Mari and Baker, Lucy (2019) The whole systems energy injustice of four European low-carbon transitions. Global Environmental Change, 58. a101958. ISSN 0959-3780

This version is available from Sussex Research Online: http://sro.sussex.ac.uk/id/eprint/85797/

The whole systems energy injustice of four European low-carbon transitions

Benjamin K. Sovacool[12*], Andrew Hook[1], Mari Martiskainen[1] and Lucy Baker[1]

* Corresponding Author, Science Policy Research Unit (SPRU), University of Sussex
Jubilee Building, Room 367, Falmer, East Sussex, BN1 9SL
Phone: +44 1273 877128 Email: B.Sovacool@sussex.ac.uk

[1] Science Policy Research Unit (SPRU), School of Business, Management, and Economics,
University of Sussex, United Kingdom

[2] Center for Energy Technologies, Department of Business Development and Technology,
Aarhus University, Denmark

Abstract: The need for multi-scalar analysis of energy and low-carbon systems is becoming more apparent as a way to assess the holistic socioeconomic and environmental impacts of energy transitions across a variety of scales and lifecycle stages. This paper conducts a whole systems energy justice analysis of four European low-carbon transitions—nuclear power in France, smart meters in Great Britain, electric vehicles in Norway, and solar photovoltaic panels in Germany. It asks: in what ways may each of these transitions result in injustices that extend beyond communities and countries, i.e., across the whole system? It utilizes a mixed-methods research design based on 64 semi-structured research interviews with experts across all four transitions, five public focus groups, and the collection of 58 comments from twelve public internet forums to answer this question. Drawing inductively from these data, the paper identifies and analyzes 44 injustices spread across three spatial scales. *Micro* scale injustices concern immediate local impacts on family livelihood, community health and the environment. *Meso* scale injustices include national-scale issues such as rising prices for electricity and gas associated or unequal access to low-carbon technology. *Macro* scale injustices include global issues such as the extraction of minerals and metals and the circulation of waste flows. The paper then discusses these collective injustices in terms of their spatiality and temporality, before offering conclusions for energy and climate research and policy.

Keywords: energy transitions; energy justice; energy policy; climate policy; whole systems

Acknowledgements: This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730403 "Innovation pathways, strategies and policies for the Low-Carbon Transition in Europe (INNOPATHS)". The content of this deliverable does not reflect the official opinion of the European Union. Responsibility for the information and views expressed herein lies entirely with the author(s).

1. Introduction

In the midst of climate change, low-carbon transitions are underway in several countries. In this paper, our aim is to explore four ongoing European low-carbon transitions—

nuclear power in France, smart meters in Great Britain, electric vehicles (EVs) in Norway, and solar photovoltaic (PV) panels in Germany—from an integrated *whole systems* and *energy justice* perspective. We ask: in what ways do each of these transitions result in injustices that extend beyond the geographic location of the transition, i.e., beyond the individual community or country, and across the whole lifecycle or system? Our mixed-methods research design is based on 64 semi-structured research interviews with experts across all four transitions, five public focus groups, and the collection of 58 comments from twelve public internet forums.

The paper is structured as follows. It first introduces our multi-scalar *whole systems* and *energy justice* conceptual framework, and then it describes our three primary research methods (interviews, focus groups, and internet forums) across the four countries. Drawing from these data, it inductively identifies and analyses 44 injustices involving three scales. As we explain in greater detail, *micro* scale injustices concern aspects that impact on local people, communities and the environment at close proximity to the energy transition or technology in question. *Meso* injustices encompass more national level impacts on policy, prices, infrastructure, and markets. *Macro* injustices relate to transnational scale impacts that go beyond nation states and relate to global supply chains and externalities. The paper then discusses these 44 combined injustices in terms of their spatiality and temporality, before offering conclusions and implications for energy and climate research and policy.

In proceeding on this path, we hope to make three contributions. The first is more empirical and methodological. Reviews of the energy justice field, such as those offered in Jenkins et al. (2016), Sovacool et al. (2017a), and McCauley et al. (2019), analyze a multitude of studies either drawing on a single case study (if they have a case study at all) or offering conceptual insights not grounded in empirical data. If they do have empirical data, it may be from experts, or members of the public, but not both. We seek to address this gap head on by offering a comparative assessment (examining four countries or case studies) using original mixed methods data collected from the “real world” via interviews, focus groups, and internet forums from a mix of experts and the public.

Second, we seek to humanize the issue of low-carbon transitions and also to reveal their underlying political economies, or trade-offs. In very simple terms: it is not only fossil fuels or large-scale systems such as hydroelectricity that can generate their own injustices; solar energy, nuclear power, smart meters and EVs can erode justice principles or create justice concerns as well. Dominish et al. (2019) as well as Jenkins et al. (2018), Xu and Chen (2019), and Heffron and McCauley (2018), remind us that low-carbon transitions are not merely technical tasks, but socially, politically, and culturally challenging processes that must be managed in fairer and more equitable ways. In line with this body of work, we seek to identify and reveal some of the ethical or moral dilemmas low-carbon transitions raise.

Third, and more conceptually, we seek to explicitly build on, and operationalize, calls for a "whole systems" or "multi-scalar" approach to energy analysis as well as energy justice. Bickerstaff et al. (2013) as well as Jenkins et al. (2014), Jenkins et al. (2017), and Jenkins (2018) affirm that energy justice needs to unbound itself by focusing on the "whole system" of a given energy technology or transition. Sovacool et al. (2017a) argue in particular that multi-scalar analyses of energy transitions are a core gap in the field and that they represents one of six "new frontiers" for research. Similar calls for multi-scalar analysis of energy transitions, though not always using the terminology of energy justice, come from Bridge et al. (2013: 337), Bouzarovski and Simcock (2017: 464), Fuller and McCauley (2016: 3), and McLaren (2012). Yet so far, multi-scalar energy research has been an emerging field within the energy social science community (Sovacool 2014). Cross and Murray (2018: 102) claim, for example, that even when multi-scalar approaches to energy analysis are taken, they "have yet to fully empirically address actually existing renewable energy products and technologies across global supply chains and product life cycles." We therefore offer a unique conceptual approach isolating injustices across three spatial scales (micro, meso, and macro) as well as temporal lifecycle stages.

2. Research design: Whole systems energy justice, case selection, and research methods

This section introduces the conceptual approach of this paper, which can be framed as one tying together *whole systems* thinking with *energy justice*. It then justifies the four case studies (France, Great Britain, Norway and Germany) and explains its research methods (interviews, focus groups, and internet forums).

2.1 Conceptual approach: Whole systems energy justice

In its most abstract conceptualization, a whole systems approach is about identifying the interactions between elements of a whole system to better comprehend, and perhaps change, the system itself; without such a systemic focus, critical components and synergies could be missed, distorting our view of system properties and obscuring implications for efficiency or sustainability (Anarow et a. 2003). However, in contrast to more conventional whole systems thinking in energy studies that has often focused narrowly on finding novel ways to reduce cost and maximize efficiency across the production life-cycle, Stansinoupolos et al. (2013: 3) argue that a whole systems approach must tackle *multiple* objectives as "a process through which the interconnections between subsystems and system are actively considered".

Unlike more formal lifecycle assessment, data envelopment analysis, or supply chain analysis, our whole systems approach extends its focus beyond a concern for cost, carbon or efficiency to embrace wider objectives such as affordability, security and social sustainability. Indeed, as McLaren (2012: 7) argues, whole systems analysis of energy systems should consider *both* the "entire life-cycle and the wider contextual environment" within which the technical system is located. Thus, rather than seeing technological and innovation processes as a closed loop divorced from social and cultural context, our conceptualization of a whole energy system means recognizing, foremost, that the origins, character, and effects of energy technologies are embedded within broader economic, social, and environmental relationships that spill across time and space (Bickerstaff et al. 2013; Bridge et al. 2018a).

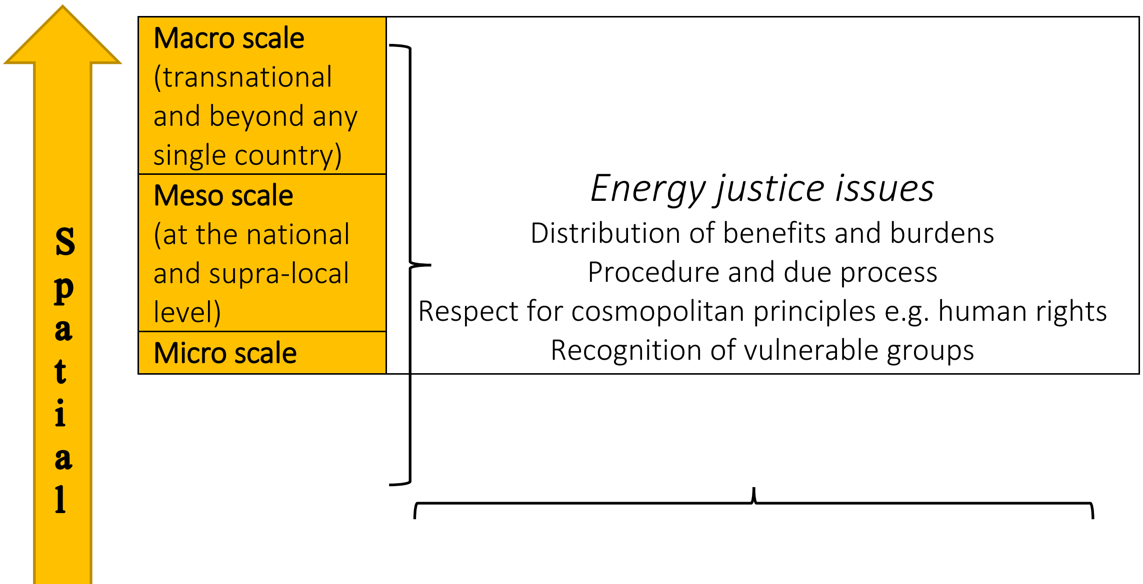
Our approach to whole systems thinking is therefore best captured by Castán-Broto and Baker's (2018: 3) notion of a relational approach: one that "prompts the need to ask systemic questions that cut across energy, geography, and society including the patterns and scales of energy supply, distribution and consumption". Such an effort "brings forward dimensions of justice, access and distribution and what this might mean for the requirements of space and territory" (Castán-Broto and Baker 2018: 3). In this sense, our whole systems lens is focused on the ways in which social, economic, political, and environmental dimensions interact across multiple scales (local, national, and global) of the production, distribution, consumption, and disposal phases of the energy process (Jenkins et al. 2014). In this spirit, Mulvaney (2013, 2014) is one of a few scholars to have taken such a multi-scalar approach, in his analyses of solar photovoltaic (PV) panels.

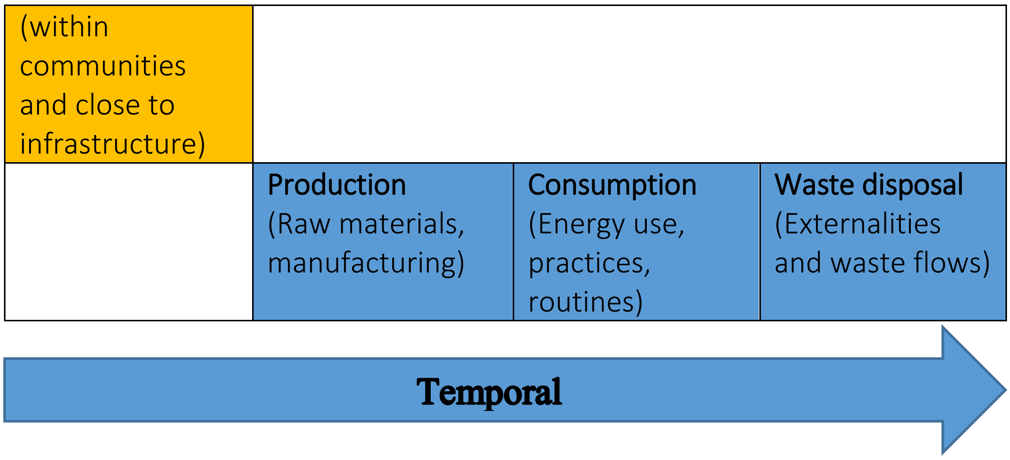
We couple whole systems thinking with *energy justice*, a normative analytical framework that demands an assessment of the costs, benefits, and procedures involved in energy decisions, pathways, and policies (Sovacool & Dworkin 2015; Sovacool et al. 2019). This can include consideration not only of vulnerability and exclusion but also those that benefit disproportionately from transitions processes (Sovacool and Dworkin 2014; Healy and

Barry 2017). We draw from Jenkins et al. (2016) who frame energy justice as asking a "what" question about the unjust impacts associated with energy systems and where they are located; "who" is most affected; and "how" do injustices become embedded in procedures or mechanisms. Energy justice therefore demands that we view the moral and ethical dimensions to energy alongside the usual technical, economic, political or, cultural ones. It also underlines that winners and losers exist within the energy system and that even a low-carbon transition can concentrate environmental hazards or unfair social outcomes among the vulnerable and geographically disadvantaged (Bridge et al. 2018b). Here, we focus exclusively on injustices with the aim of making them more identifiable so that future research and policy can plan for and perhaps minimize them.

In summary, when applied to the four low-carbon transitions we examine, whole systems thinking demands we look across spatial and temporal scales to understand the burdens and procedures that may systematize injustices (Healy et al., 2019). Energy justice meanwhile demands that we look at impacts on communities that are – or may become – vulnerable. We interpret this to mean we must look at multiple dimensions of a transition (technical, economic, social, political, etc.), multiple lifecycle stages of the technology involved (including material inputs, manufacturing, use, and disposal), and groups that may be or become vulnerable at multiple spatial scales or moments of the transition. Because numerous studies, including Alberini et al. (2018), Hiteva and Sovacool (2017), Balbus et al. (2014), Burke et al. (2018), Noel et al. (2018) and Ürge-Vorsatz et al. (2014), have already focused *only* on the benefits (or the positive justice co-benefits) of low carbon transitions, here we take a critical lens that seeks to examine and reveal injustices. Our whole systems-energy justice approach is illustrated in Figure 1 below.

Figure 1: Whole systems-energy justice conceptual framework





Source: Authors

To operationalize our whole systems-energy justice approach, we utilize three analytical scales: micro, meso, and macro. While these scales can be open to different interpretations, by *micro* scale, we refer to injustices that occur within a particular community or household that is located to close proximity to the energy innovation or system involved in the transition. By *meso* scale, we refer to injustices that cover more national level consequences for policy, technology, or markets. By *macro*, we refer to injustices that occur and circulate at the regional, transnational, and global scale. This micro-meso-macro framing has been used extensively in other fields, notably evolutionary economics (Dopfer et al. 2004), innovation studies and technology analysis (Jamison and Baark 1990), health studies (Kapiriri et al. 2007), and environmental studies (Liljenstrom and Svedin 2005), but has not been applied to energy justice analysis. We also draw on the transitions field, recognizing that low carbon transitions are geographically-constituted processes (Bridge et al., 2013), and that there is a need to go beyond nationally bounded case analysis (Raven et al., 2012). Even though we differentiate between micro, meso and macro scales, we recognize that these scales are interdependent, geographically uneven (Coenen et al., 2012), and that there is no necessary hierarchy between them. Moreover, such terms are meant to convey a sense of spatial scale only, they are not meant to imply any absolute or relative degree of importance. All three scales of injustice—micro, meso, and macro—are significant.

2.2 Case study selection

With our whole systems-energy justice approach established, we then sought to select four strong examples of European low-carbon transitions, e.g. areas where European countries are regional or global leaders. These can be regarded as leading case studies that offer a degree of temporal variation and different types of energy transitions (two supply oriented such as France and Germany, two focusing on end use devices such as Great Britain and Norway).

France is well known for its nuclear power transition: with the second highest share of nuclear reactors in the world (after the United States) it is also the largest exporter of nuclear power in the world and is one of the largest recyclers of nuclear fuel (World Nuclear Association 2018). Although initially launched for economic and national security reasons, the French nuclear case has more recently been framed as a "low carbon energy transition" (Araújo 2017).

Great Britain has one of the largest smart meter programs in the world and is currently seeking to install 56 million smart meters for electricity and gas in all homes and small businesses across England, Scotland and Wales by the end of 2020 (House of Commons Science and Technology Committee, 2016).

Norway is the world leader for the per capita deployment of EVs; it has the highest annual growth rate of EVs in the world (up 57% from 2016 to 2017); and it has the highest market share in the world of EVs as a proportion of new car sales (International Energy Agency 2018).

Germany has the greatest total installed capacity of solar PV per capita anywhere in the world and has also pushed decentralized solar generation among households, where more than 1.5 million residences have adopted their own solar PV system (German Federal Ministry for Economic Affairs and Energy 2017; Wittenberg and Matthies 2016: 200). These cases also represent different timescales of when national policies supporting the specific energy technologies were introduced (nuclear power in the 1970s, EVs in the 1990s, solar PV in 2000s, and smart meters in the 2010s).

2.3 Mixed methods research design

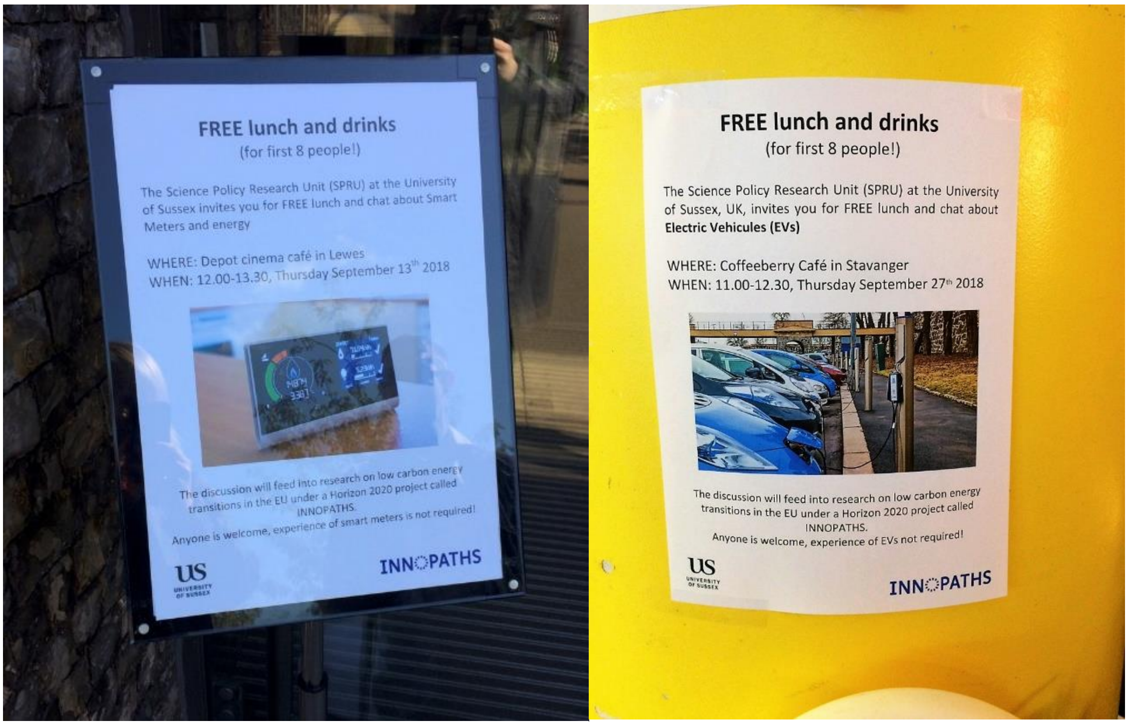
To collect original data across these four cases, we proceeded with a qualitative research design that used mixed methods across expert research interviews, public focus groups, and public internet forums. We conducted 64 interviews with experts between June and August 2018, 16 for each of our case studies, with interviewees selected to represent a diverse mix of institutions such as those within:

- Industries, industry associations, and private sector firms such as Electricité de France, the German Solar Association (BSW-Solar), the Federation of Norwegian Industries, and Smart Energy GB in the United Kingdom;
- Non-profit groups and civil society organizations such as Greenpeace in France, E3G in Germany, the Norwegian Electric Vehicle Association, and Citizens Advice in the United Kingdom;
- Regulatory and government entities such as the Commissariat à l'Énergie Atomique et aux Énergies Alternatives (CEA) in France, Federal Ministry for Economic Affairs and Energy in Germany, the Ministry of Transport and Communications in Norway, and the Department for Business, Energy & Industrial Strategy in the United Kingdom;
- Universities and academic institutes such as the ESSEC Business School in France, Fraunhofer Institute for Solar Energy Systems in Germany, Norwegian University of Science and Technology in Norway, and the University of Oxford in the United Kingdom.

In each interview, we asked (among other questions): “What do you see as some of the most significant costs or disadvantages to the energy transition being examined?” And, “Taking a whole systems perspective, who or what may be the biggest losers beyond Europe?” The research interviews generally lasted between thirty and ninety minutes, were digitally recorded, and participants were guaranteed anonymity to protect their identity and encourage candor.

To supplement our expert interviews with public perceptions and experiences, we conducted five focus groups in non-capital areas of each country, namely Lewes (UK), Colmar (France), Freiburg (Germany, 2 groups), and Stavanger (Norway). Unlike the interviews, which involved experts and were mostly done in national capitals, we intended the focus groups to capture public perceptions in non-urban areas. As Figure 2 indicates, these were entirely open to the public, and we collected responses from a total of 15 participants.

Figure 2: Focus group recruitment posters for Falmer, United Kingdom and Stavanger, Norway, September 2018



FREE lunch and drinks
(for first 8 people!)

The Science Policy Research Unit (SPRU) at the University of Sussex invites you for FREE lunch and chat about Smart Meters and energy

WHERE: Depot cinema café in Lewes
WHEN: 12.00-13.30, Thursday September 13th 2018

The discussion will feed into research on low carbon energy transitions in the EU under a Horizon 2020 project called INNOPATHS.
Anyone is welcome, experience of smart meters is not required!

FREE lunch and drinks
(for first 8 people!)

The Science Policy Research Unit (SPRU) at the University of Sussex, UK, invites you for FREE lunch and chat about **Electric Vehicules (EVs)**

WHERE: Coffeeberry Café in Stavanger
WHEN: 11.00-12.30, Thursday September 27th 2018

The discussion will feed into research on low carbon energy transitions in the EU under a Horizon 2020 project called INNOPATHS.
Anyone is welcome, experience of EVs not required!

Source: Authors

Lastly, to triangulate our interviews and focus groups, which were limited to Lewes, Colmar, Freiburg, and Stavanger, we posted research questions on twelve sector specific online internet forums summarized in Table 1. These internet forums had more than 2 million collective members, meaning they were open to a large block of possible respondents and helped hedge against the possible bias in our expert interviews and limited location of focus groups. In other words, the forums were the method mostly accessible to the public. In the forums, we asked: "What are the biggest advantages of low-carbon innovations such as smart meters/EVs/solar energy/nuclear power? Who are the big recipients of those benefits or winners?" This resulted in 58 additional responses collected by the forums shown in Table 1.

Table 1: Summary of public internet forum discussions

Country case study	Forum	Description
Norway	Elbilforum.no	Norwegian EV forum
	Tesla motors club Norway	Online forum for Tesla owners in Norway
	SpeakEV	Online electric car forum for all EV owners and enthusiasts
Germany	Photovoltaik forum.com	A solar forum in German
	Solarstrom-forum.de	A solar photovoltaic forum in German
	Building Technology Forum - Solar Energy	Online forum for all building technologies including solar

United Kingdom	Money Saving Expert	Consumer forum
	Navitron	Private company forum on a range of energy issues
	OVO Energy	Private company forum on a range of energy issues
France	Que Choisir	Consumer forum
	Forum photovoltaique	Energy forum
	Droit Finances	Consumer finances forum

Source: Authors

After collection of the interview, focus group, and internet forum data, they were fully transcribed, and then coded by two researchers, with each respondent given a unique identifying number. Our coding scheme was exhaustive and inductive, meaning we coded every response and then analyzed the full sample using NVivo.

2.4 Limitations

Despite an attempt at triangulation within these methods, our approach does have some notable limitations. Although the focus groups and internet forums were open to all members of the public, the number of responses collected was less than that of the expert interviews. Our interview questions asked explicitly about “injustices,” but these can be real or perceived, historical or prospective, and they can vary by degree, i.e. encompassing issues, tensions, challenges, and costs. What some consider an insult, injustice, or harmful act may be perceived by others as a mere inconvenience or annoyance. What is important is that such aspects were nonetheless *perceived* as injustices by our respondents. We therefore do not want to marginalize respondents, or induce non-recognition (e.g. Jenkins et al. 2016), by seeking to challenge them on the severity of the injustices identified.

Furthermore, due to the wealth of empirical material spread across four case studies, we did not have sufficient space in this study to also assess benefits, co-benefits, or positive synergies, or to conduct a rigorous literature review to contextualize or triangulate our findings, although we do explore those domains in other papers.

Lastly, we did not make an attempt to weight, correct, normalize, or problematize data across our methods, to avoid censoring our results and discussion. Perhaps some of these weaknesses, especially confirmation with the peer-reviewed literature or complementing our analysis with quantitative techniques, indicate directions for future research.

3. Results: The whole systems energy injustices of four transitions

In this section, we present our core results across the three methods (interviews, focus groups, and internet forums). Guided by the whole systems-energy justice approach, we explore environmental, social and economic injustices across three primary scales: micro scale (households and communities); meso scale (across a nation or subnational region); and macro scale (transnational, regional and global ramifications). Admittedly, such scalar categories are relational, so here we ground the discussion with Europe as the central unit of analysis. Such injustices would obviously be regarded at inverse scales in other areas (i.e., uranium mining would be macro to the French transition but micro to the communities hosting the mines). The four respective low-carbon transitions in European countries are thus the geographical "anchors" for our analysis.

3.1 French nuclear power

The injustices associated with nuclear power in France include micro issues such as risks facing communities living near nuclear infrastructure and waste, meso issues such as pollution and accident risks, and macro issues such as uranium mining and milling.

3.1.1 Micro injustices

At the micro scale, respondents emphasized the scope and severity of local level environmental, health and economic impacts. F001 focused on interrelated environmental impacts such as water consumption for cooling, nuclear waste, and health, stressing the strong spatial dimensions of these vulnerabilities:

> *France will have to close down inland reactors as the rivers lose water volume, and you cannot get the cooling. We know what will happen to the reactors on the coast with rising sea levels as rising storm surge may flood and create nuclear islands … France's radiological inventory, because of the weight of its nuclear power is enormous. I was up in Le Hague, and they have a waste problem even worse than the UK. They are running out of space for intermediate storage. Then, there are classic health and environmental vulnerabilities.*

F006 emphasized the local nature of these types of environmental and health impacts, stating that people living near nuclear plants were more exposed to nuclear risks than others, making it also a moral – and existential – burden for them. F014 meanwhile noted that for those living near nuclear plants, there was a trade-off between personal economic benefits and nuclear risks, which could create vulnerability: "*People have been manipulated into accepting potentially dangerous plants in their communities in exchange for jobs and investment, so potentially they are most vulnerable if there is an accident.*" Other respondents talked about particular communities and sectors that had become vulnerable over time, such as those owning property near power plants. As F011 explained, "*The problems are more visible and there is a moving population that is less connected to the plants. People who could afford it have moved away and the prices of property in the vicinity of plants has fallen, leaving those with homes disadvantaged."* F006 contended that nuclear plants had impacted negatively on some agricultural sectors, notably wine making, with wine growers apparently "*very resistant to nuclear development."* This point was also picked up by F011, who claimed that "*wine growers in areas such as Bordeaux, whose vineyards were in the vicinity of plants were affected. In other areas, such as Golfech, near Toulouse, there is radioactive material in the water supply*." As the second largest wine producer in the world (OIV, 2018), the French wine industry has a considerable reputation to protect.

F002 suggested that such issues may be part of a systematized process of peripheralisation within France that creates natural vulnerabilities for certain communities, leading to "*inequality*" and community "*ambivalence*" to environmental threats. The issue of local environmental impacts was also raised in the focus group, with a respondent noting issues with radioactive leaks: "*In the Rhone Valley, they have radioactive leaks, but this is not being reported. It remains a secret, they do not talk about it. But even at Fessenheim they have not minimized these problems.*" This statement was confirmed by Institute for Radiological Protection and Nuclear Safety in France (ISRN 2014).

Micro scale injustices in the French nuclear case tended to dominate the discussions across all three respondent groups, which may reflect the fact that those interviewed view local threats most acutely since they are the most exposed to them. In the case of nuclear power, plants are often visible in local communities through a legacy of providing jobs and investment in local facilities, but also through local protests against nuclear waste management (F007) (see Figure 3).

Figure 3: An "anti-nuclear power" emblem car sticker in Colmar, France, July 2018

Source: Authors

3.1.2 Meso injustices

At the meso scale, respondents repeatedly referred to the risk of accidents and the potential ways in which France's nuclear pathway has interfered with the development of other low-carbon innovations and transitions.

In terms of accidents, F007 stated that accident risks threaten the whole of France, while in the internet forums, one participant noted: "*The negatives to nuclear power in France are clear. They include the long-term and immediate ecological risk of a single nuclear accident.*" The risk of an accident is difficult to predict, but probabilistically could occur at any facility and at any time (Wheatley et al. 2017), with F007 stating that "*They wanted to build 200 reactors, and we only built 58 and that is 58 opportunities for accidents*!".

A second important dimension relates to the ways in which the presence (and predominance) of French nuclear power potentially interferes and interrupts other energy transitions. As F007 explained: "*Italy benefitted from cheap French nuclear electricity but that surely didn't help it to build and develop its own sound strategy for its own energy system*."

F012 explained this dynamic in more detail, noting implicitly that it cuts across meso and macro scales:

> *Because France delivers a lot of baseload power to its European neighbors, and the fact that France needs to protect its export industry, means that France has had to slow down the development of renewables in other countries. Moreover, the large amount of baseload France gives to other countries is slowing down the capacity of the grid to exchange the renewable surplus to other countries. For example, Spain and Portugal are completely blocked by the fact that they can't have the flexibility of selling back to France.*

These meso scale injustices relate to nuclear accident risks affecting the whole of France despite the location of nuclear plants, and an impact on the wider renewable energy transition.

3.1.3 Macro injustices

At the macro, or global scale beyond Europe, respondents drew attention to the potential risks that nuclear accidents pose to countries beyond France and the transnational nature of environmental and social injustices, particularly those related to uranium mining and nuclear exports.

In regards to the risk of nuclear accidents, F004 argued that these risks also go beyond national borders. This macro dimension was echoed also by F001, who stated that "*if an accident happens, depending on which way the wind is blowing, that will determine who is affected*," with "*The English Channel, Belgium, the Netherlands, and Scandinavians*" all at risk. F007 also highlighted the risk of accidents for neighboring countries, especially regarding environmental injustices:

> *Environmental accidents do not stop at the border. From an environmental justice perspective, a small country like Luxembourg could just disappear if Fessenheim has an accident! Belgium too! When we think about environmental justice we assume, in very economic terms, that it is only the polluters who will have to pay the costs, but a wider range of people will be affected.*

In terms of injustices related to mining, F011 for example stated that: "*In Niger and Kazakhstan, there is the buying of uranium and the conditions of workers and the political systems there is a justice issue*." France uses approximately 12,400 tons of uranium oxide concentrate (10,500 tons of U) per year and imports this mainly from Canada (4,500 tons of

Uranium/year (tU/Y)) and Niger (3,200 tU/yr), with the rest coming from Australia, Kazakhstan and Russia (World Nuclear Association 2018). This issue of uranium extraction was also highlighted in the internet forums, where a respondent indicated: "*The issue of the extraction of uranium is a serious risk, but that is also why we try not to talk too much about it!*" F007 commented on the potential problems linked to selling nuclear technology to other counties that have more unstable political settlements and laxer environmental protocols:

> *France has sold nuclear technology to countries where it was really a problem to implement. In a country with a strong democratic basis, at least you have strong governance and counter powers. But in places like China, if tomorrow if there is a problem, it will be a disaster. In Russia, we are now sure that uranium is leaking and local surroundings have been heavily contaminated. Regulatory bodies like the IAEA reflect the powerlessness of international governance, they have been completely unable to demand an inquiry. Essentially, France has shown to other countries that the centralization of political power is a prerequisite for the development of nuclear. French companies have tried to even sell nuclear technology to countries such as South Africa or Libya, under the Gadhafi regime.*

The macro scale injustices related to French nuclear power illustrate the geopolitical and transnational nature of the risks of the French nuclear industry, and the extent to which the impacts of decisions made in France have implications for other countries, notably those where resource extraction takes place.

3.2 British smart meters

Our material identified various social, economic, and environmental injustices related to the British smart meter roll-out. Micro scale injustices related to the exclusion of rural areas and hard-to-reach groups, more expensive household bills, and added stress for families; meso injustices related to job losses in incumbent sectors; and macro injustices related to issues such as waste streams and the potential (and paradoxical) contribution of the program to global carbon emissions.

3.2.1 Micro injustices

Although the national smart meter program is attempting to minimize such instances, respondents suggested that there may nonetheless be inevitable geographic exclusions of customers in some rural areas, particularly in Scotland, meaning that not everyone would benefit evenly from the smart meter program. As GB005 noted:

> *There is quite a strong geographical inequality in what is going on. It is unlikely that smart meter coverage works in rural and remote areas. At the moment, with SMETS 1 [first generation] meters, you're relying on the equivalent of cellular network coverage, which is just as unreliable as mobile phones in those areas … People in rural areas are going to miss out on the advantages to smart meters … In the highlands of Scotland, network coverage is terrible, and it's the same with smart meters*.

GB006 even estimated that there was a proportion of homes that may be permanently unable to accommodate a smart meter due to their location: "*Our analysis suggests that 85% of homes fit the needed categories of being able to adopt smart meters—they have the necessary networks, meter availability, etc. But the other 15% in rural areas or a block of flats are excluded by those criteria*." These hard-to-reach groups also potentially include people living in mobile homes and those living in certain apartment blocks (GB015). They may also include lower income people who cannot afford to acquire – or who do not have access to – supporting innovations, such as automated appliances or smart homes. Potential exclusion was also mentioned in our internet forums, where respondents thought that limited access to mobile network coverage could lead to the non-functionality of meters: "*Smart meters do not work in areas with no or poor mobile data coverage.*"

Another important micro scale concern was that energy bills may become more expensive as a result of the smart meter program, particularly if people were not able to change or shift their energy demand. As GB010 explained:

> *Via smart meters, certain people have more ability to respond to time of use tariffs, and have either more flexibility for them to shift their loads to other times, but also in terms of installing systems that will automatically do that on their behalf. However, those people who do not respond to the changing tariffs structures could find themselves worse off.*

Respondents in the focus groups suggested that apart from negative monetary impacts on families, smart meters could also erode family unity and lead to tensions: "*People with teenage children could suffer from smart meters. Teenagers use a lot of electricity if they have all got computers, playing games in their separate bedrooms. Possibly families with children could lose out, at the least it could cause tension!*" This theme was also mentioned in the internet forums, with a respondent recounting a story about a smart meter leading to a fight with his wife because she had baked cakes and scones only to cause a "*red light event*."

In sum, the technical and geographical issues relating to smart meter access could potentially create a digital divide at the micro scale between those homes who have access to smart meters and those who do not, leaving some homes unable to access potential benefits from smart meters. Furthermore, the way in which consumers engage, or do not engage, with smart meters could have a profound impact on the way in which their bills take shape in the future.

3.2.2 Meso injustices

At the meso level, respondents discussed economic and environmental injustices, mainly in the form of raised overall energy bills, job losses, and the environmental impacts of the smart meter roll out (including carbon emissions from the installation process).

A significant number of respondents across all data sources expressed concerns about the expense of the national smart meter program. Although the up-front costs are being borne by suppliers, most suspected that consumers would end up paying for the program in the end. As GB001 summarized: "*companies will have to pass on the costs somehow, so there's clearly a justice/distributional thing there, with likely higher bills*."

On job losses, some suggested that incumbent actors in the "*MOP and MAP*" services would be major losers from the smart meter transition. This is an industry term that refers to different actors in the energy metering system: MOP refers to the "meter operator" and MAP refers to the "meter asset provider," who is responsible for maintaining and installing metering equipment. We classify these as meso rather than micro since they affect primarily national energy companies across the entire country. As GB007 stated: "*As a direct loser in the transition, I suppose the meter readers will lose their jobs*." GB002 estimated to their knowledge that this would affect approximately 10,000 employees. Taking a more system-wide lens, GB012 hypothesized: "*I suppose the losers of a sustainable, smart system are basically the gas industry, because we shouldn't really be using gas after 2040, so then it's more the kinds of people working in the gas networks, all the suppliers*."

Although one of the ultimate aims of the smart meter program was an end to the carbon-intensive practice of meter-reading, a number of respondents commented on potential paradoxical rises in national carbon emissions that could result from the smart meter roll-out, at least compared to a different programmatic design, with GB003 linking this environmental externality with the fragmented structure of the energy sector in the UK:

> *The smart meter program in the UK is more complex than other countries. Those countries do it geographically, street by street. Here, in a street of 100 houses, you could have 100 different suppliers. It will be sporadic, because it involves 100 separate journeys, and using a lot of carbon driving around.*

GB006 also raised this issue, stating that: "*An optimal way to deploy smart meters would have been street by street, town by town. Instead, here you have six different vans going to the same street, and therefore six times the environmental cost. You have vans full of meters driving up and down the country*."

The meso scale injustices of the smart meter roll out show how the practical delivery of low carbon solutions can cause unwanted impacts at national scale in regard to costs and emissions. While some of these are shorter lived (e.g. emissions linked to smart meter installations) other can have longer-term impacts (e.g. job losses).

3.2.3 Macro injustices

At the macro level, respondents emphasized potential environmental injustices linked to waste streams associated with the manufacturing of smart meters (and in-home displays) as well as afterlife issues related to old meters such as recycling and electronic waste. Perhaps reflecting the "*invisible*" nature of these global supply chain injustices, several respondents conceded that they had received little information about the manufacturing and recycling processes of the smart meter rollout (see also Alexander & Reno 2012; Sovacool et al. 2017).

GB001 for example speculated about both the source – and end place – of smart meter components: *"Smart meters involve a lot of 'stuff'. The materials impact could be considerable. And how much are you relying on metals from war torn countries?"* GB008 put it this way:

> *Where the actual hardware is being manufactured could be an injustice. I do not know where the meters are being manufactured nor where the meters that are being removed are being disposed of or recycled. From what I know about mobile phones, I suspect that it is quite an environmental and social burden, especially on countries outside of Europe.*

GB012 added that: "*By my estimate, we put in 5 million meters already which are pretty much old fashioned, and we're putting in another 7 million meters that are nearly old fashioned. This is all resource intensive*." GB016 meanwhile posited that: "*If you think of the in-home display and environmental impact, it's another digital device in people's homes, another thing that they don't necessarily need that will be eventually recycled, managed and wasted*." The macro scale injustices of smart meters thus links to the globalized production of goods where material supply chains can be complex and untraceable (Bridge et al. 2018c).

3.3 Norwegian electric vehicles

Our material in Norway identified micro scale environmental and social injustices in the form of increased traffic and pollution, a lack of parking spaces, a general growth of cars, and a lack of infrastructure in rural areas. Meso scale injustices included the potential encroachment of roads into ecologically sensitive areas. Macro issues related to issues such as global waste streams, foreign resource extraction and industrial activity, and the exporting of second-hand cars.

3.3.1 Micro injustices

Micro issues centered broadly on two topics, the environmental and social injustices of increased local car use (and thus corresponding emissions, congestion, parking, and reduced walking and physical activity) and the geographical exclusion caused by a lack of EV infrastructure in rural areas. N015 explained the impacts of growth in EV use in urban areas:

> *We have exponential growth in EV passenger cars in Norway and particularly in the bigger cities. There is obviously a clear conflict down the line in that cities cannot take a higher number of cars and EVs which take exactly as much space as a diesel or fossil car.*

This issue also arose in the focus group: "*If you move from public transport to EVs, then I can understand concerns about traffic, congestion, and parking in Oslo. We could even see traffic increase to unsustainable levels*." In the internet forums, one respondent noted they started driving *more* now that they had an EV, highlighting an unintended impact of EVs:

> *Since EVs are clean and less polluting, I don't feel so bad about using a car for short trips. This means that I tend to use the car (instead of a bike or a wheelchair) to go everywhere, even less than 1-2 km away. Even though deep down, I know that it is every bit as dangerous for pedestrians and cyclists as a fossil car.*

As well as these issues resulting from the increase in EV use, N004 drew attention to the differentiated benefits – and potential exclusions – that currently appear inherent to the EV expansion in Norway, with certain rural geographical areas not benefitting as much from EVs as urban cities. N011 emphasized the vulnerabilities related to rural (and winter) EV usage in Norway, touching on the contemporary and contentious issues of "*range anxiety*," noting that "*There is obviously a problem with electric mobility in the countryside*." Respondents in our internet forums agreed, noting:

> *By far, the biggest issue with EVs is how to charge it up if you live in a place without a private parking spot or a charger. This is a difficult problem to solve. Another issue is to have enough fast chargers when you drive long distance. Occupied or broken chargers are a bigger problem than range anxiety.*

Another commented that: "*The EV transition disenfranchises those who are not living in urbanized areas, because range is a big factor. So some rural people feel 'left behind' in this EV revolution*." Essentially, this means that EVs may be good for taxi fleets and private companies in urban areas (see Figure 4) while being beyond the reach of most rural consumers.

Figure 4: A Tesla Taxi in Trondheim, Norway, March 2018

Source: Authors

The identification of these micro scale injustices highlights how socio-technical issues related to the roll-out of EVs and the development of supporting infrastructure have strong geographical dimensions. Indeed, respondents suggested that there is a profound urban-rural divide between those who can benefit from EVs in cities and those who cannot take part in the transition but are left to drive polluting (and increasingly taxed) petrol cars in rural areas.

3.3.2 Meso injustices

Meso scale injustices of the EV transition in Norway related to how people reliant on public transport and fossil fuel cars are being hit with more national taxes – while also not being able to afford an EV. This came up in five interviews. Another meso concern linked to debates around the expansion of roads, especially in ecologically sensitive and nationally protected areas. N007 argues here for example that the environmental credentials of EVs are being used to justify greater expansion of the road network:

> *Norway … still has 94% of diesel and petrol cars. There are some politicians who think now that the environmental problems have been 'solved' with EVs and that we can do all other things, like build roads, which also harms the environment in other ways … In a way, EVs allow for the greenwashing of road building and expanding road transport … There are even plans to build a highway that stretches in areas of important nature and wetlands that have high environmental value. They have for example decided to go into a protected area near Lillehammer. Also, on the west coast they want to build a highway to Trondheim, to the whole west coast, over the fjords. Many of the people who are pro this say that EVs make this less harmful for the environment.*

N011 meanwhile highlighted the problems related to road building in terms of increased national traffic, adding:

> *Infrastructure for cars, including EVs, is one of the main reasons for the loss of biodiversity in Norway in general. If you build more efficient roads you get more road traffic and … you get more of those problems with noise and dust from the road and plastics. Since the cars are still not fossil free in this transition period, we still increase our emissions by investing in more roads.*

The meso scale environmental injustice of using EVs as a justification for new road building plans shows how a benefit in one area (a less polluting car) can be used as to rationalize policy in another area that leads to arguable ecological harm (biodiversity loss due to road building).

3.3.3 Macro injustices

Respondents lastly identified social and environmental macro scale issues such as waste flows generated by and externalities resulting from foreign manufacturing processes that underwrite Norwegian demand for EVs, as well as the exporting of 'dirty' (fossil fuel-powered) cars out of Norway.

N001 noted this transnational link between the Norwegian EV and the extraction of necessary minerals in other countries: "EVs do directly have negative consequences in the Democratic Republic of Congo, and also Latin America [Argentina and Colombia] where lithium and cobalt come from." N006 reflected on some broader (and hitherto under-studied) dimensions of the EV revolution in Norway:

> *There are things with battery production that are of concern. Scarce materials, terrible working conditions for people in mines in the Congo where they have to get cobalt from. And the disposal of the batteries at the end. There is a risk that this leads to environmental disasters somewhere else, so that we can drive around in clean cars in Norway only by exploiting even more poor workers in third world countries than we do today.*

Other respondents also touched on the problems related to battery manufacturing, including "*severe*" environmental impacts from mineral extraction and social impacts of using "*child labor*." N004 meanwhile highlighted the spatial justice trade-offs between Norway's 'green' consumption and the potentially 'dirty' production that occurs somewhere else: "*EVs only make Norway green because they are produced somewhere else, and they are very energy intensive to manufacture*."

Beyond the EV production process, N004 also connected EV use in Norway with the exporting of (soon-to-be-outlawed) fossil fueled cars, soon to be outlawed (Kass 2018), and second-hand cars towards jurisdictions with weaker environmental standards. They speculated:

> *The EV transition in Norway does create a risk that – we see that with computers and mobiles – the fossil fuel cars they are replacing are dumped in markets in developing countries for example at a cheap price and that is a risk to the environment and climate.*

N011 noted that damaged EVs (and other cars, which have been displaced by EVs) can end up in foreign markets. Figure 5 for example shows discarded European and Nordic vehicles and parts at a lot for sale in Accra, Ghana.

Figure 5: Used European and Nordic cars (and car parts) for sale in Accra, Ghana, February, 2019

Source: Authors

These macro scale injustices highlight the potentially uneven nature of low carbon transitions, where benefits in one country can in fact result in injustices in others. Issues such as the use of child labor in cobalt mining in the Democratic Republic of Congo (e.g. Heffron, 2018), poor environmental standards of battery production, and other nations possibly acting as waste grounds for old Norwegian fossil fuel cars, show how the Norwegian transition to EVs has far-reaching implications that are felt far beyond the borders of Norway.

3.4 German solar panels

Our material on the solar PV transition in Germany highlighted the micro injustice of the exclusionary nature of investing in the feed-in tariff (FIT) scheme and unemployment and labor issues at German solar firms; meso injustices such as the erosion of the market vitality for nuclear power and coal; and macro injustices such as negative repercussions on neighboring countries Poland and the Czech Republic, threats to European electric utilities, the disruption of global fossil fuel markets, the extraction of raw materials, and poor working conditions at overseas manufacturers of solar equipment.

3.4.1 Micro injustices

At the micro scale, respondents identified two main injustices: those unable to afford investment in the national solar feed-in tariff (FIT), and the impact of renewable energy transition on both coal miners and former solar manufacturing employees.

Although half of renewable energy is citizen-owned in Germany (Johnstone & Kivimaa 2018), one stream of economic injustices that respondents drew attention to was the potentially uneven access among German citizens to solar resources and financing, with a focus group respondent noting plainly that: ”*If you don’t have the money you can’t invest in the solar revolution*.” Considering that the consumers who have been able to benefit from generous subsidies are the ones who have been wealthy enough to afford the panel set-ups, in this light, the German solar transition could be seen as an example of the poor cross-subsidizing the wealthy, good for community halls in wealthy areas (see Figure 6) but not accessible for those on low incomes.

Figure 6: The Vauban community hall with solar PV, Germany, September 2018

Source: Authors

This exclusionary aspect of solar energy was identified as also having geographical dimensions, with G006 observing that there may be interlocking meteorological and socioeconomic dimensions to the exclusion of some from solar, as it inevitably does not work well in less sunny areas or for those whose access to sunlight (and personal roof-space) is limited by the fact that they live in flats and apartments:

> *Since we all know solar PV is powered by the sun, people living in places with fewer solar resources are at a disadvantage, or those living in buildings without [access to] a roof, or without a roof facing the right direction.*

There are further geographical dimensions to the injustices felt by some in Germany, with G001 claiming that populations in Eastern Germany, for example, feel resentment and anger towards the solar policy:

> *In East Germany there is recent living memory of losing out, because of the closure of Eastern German industry and nothing coming to replace it. They feel that they are the victims and they regard the market, the government and its pro renewable energy policy as evil, making them victims. The idea that they are helping others get rich is entrenched.*

For G005, resentment is sharpened further by the fact that coalminers are an already-marginalized (and beleaguered) community within Germany:

> *The high carbon fossil fuel industry is obviously and rightly threatened by solar energy, they lose their business model. Other social costs include the closure of coal mines and coal power plants in eastern Germany … If these companies leave and the jobs leave, you need create credible solutions for these people to buy into a low carbon pathway. And this so far has not happened. Instead, the beneficiaries of solar have been companies in the South of Germany, notably Freiburg in Baden-Württemberg.*

G008 reflected on the legacy impacts that Germany's declined solar sector has had, particularly the fate of the large number of workers who lost their jobs following a bust in German solar manufacturing:

> *Interestingly the real vulnerable group from the solar transition is not often talked about, namely 100,000 people who lost their jobs in the German solar sector over the past years. You have trade unions and government going, oh my goodness, we cannot shut down coal because of all the work and these regions. Yet Solar World and other big producers have shut down in the past years and they didn't make a peep about those workers. Workers in the German renewable energy sector are a vulnerable population. Some have poor labor conditions and terrible contracts.*

These micro scale injustices demonstrate the unevenness of the German solar PV transition in terms of who has been able to benefit – both temporally and spatially.

3.4.2 Meso injustices

At the meso scale, respondents cited the challenges that solar presents to centralized energy supply, and the impacts of Germany's fading solar manufacturing boom.

Decentralized solar PV has presented an inherent challenge to (incumbent) centralized power providers, especially nuclear operators, as well as coal-fired power stations. As G010 put it: "*The nuclear industry in Germany has been suffering from the decision to phase in solar, and phase out nuclear. They are forced to explore options to sell overseas, given they no longer have a home market*."

Reflecting on the temporal specificity of Germany's (since-faded) domestic solar manufacturing boom, some respondents argued that the solar transition has even (oddly) created risks for the market as a whole. G002 put this in the context of competition and bankruptcy for German firms:

> *Germany has changed the economic value chain for the solar industry, not necessarily for the better. Solar panels are not produced anymore in Germany …. To compete, German manufacturers tried to decrease their prices. However, that was not really efficient then and they went bankrupt.*

G013 lastly noted that solar companies perhaps lost the most in the German transition due to a watering down of national policy and negative perceptions from financiers, in some cases leading to "*many companies*" going into "*insolvency because the banks no longer finance solar projects."* Consequently, it is apt to conclude that, in spite of it being considered a "success story" of state intervention, these gains are not permanent and indeed the German solar sector itself has not been immune from the changing nature of the transition and the whims of global markets (Meckling & Hughes 2018), which shape the national transition dynamics related to solar.

3.4.3 Macro injustices

At the macro level, respondents drew attention to several concerns with the solar PV transition in Germany, particularly negative impacts on Germany's neighbors, and the negative economic impacts on global fossil fuel providers and the potential environmental and social impacts of the (overseas-based) panel production process.

G010 framed the solar transition in terms of creating disruption to conventional energy suppliers across Europe:

> *Some of the losers are the conventional utilities across Europe because their business model has been eroded: a strong increase of renewables erodes their market share, and also because of the access to the grid, thus making the baseload power plants not economic or workable, though they still have to be around to cope with situations when renewables cannot be relied up.*

G011 added that:

> *Countries like Poland and the Czech Republic are angry about our solar transition because they are now suffering from cheap electricity imports from Germany. Coal plants in Poland and nuclear plants in the Czech Republic have had to reduce output and sell less electricity because of cheaper exports from the German grid.*

In the focus group, respondents stated that the German experience may have even created a negative stigma against future investments in a European solar industry: "*The main negative to the solar transition is the loss of the companies who wanted to manufacture solar panels* *but have shut down. The lesson appears to be it is difficult to make a profit doing solar in Europe."*

As per impacts on global fossil fuel providers G001 argued that, although this would not be seen as a bad outcome by many, fossil fuel states and companies themselves are nonetheless set for huge disruptions as a result of the German (and global) PV transition:

> *The people who benefit from the fossil fuel industry are the biggest losers. I do not feel sorry for them, because it is like the drug dealer complaining about losing his business, or the burglar. But there is logic in the claim that they are losers to the German transition … Petrol states like Venezuela, which is going bankrupt, could be vulnerable as global oil markets shrink. Canadian oil sands is in a similar category.*

G003 concurred with this analysis, noting "*countries who export coal like Australia or South Africa are at risk, as well as oil and gas producing countries, especially in the long run. In other countries like China and India, you will see a huge growth of carbon intensive technologies to produce energy, so they could lose out also when renewables disrupt those markets.*" These apparent threats to incumbent sectors seem apt given that Germany is rapidly electrifying transport (meaning solar can begin to "substitute" for oil) (Canzler et al. 2017) and that it currently still imports 55.2 million tons of coal per year, or 93 percent of its hard coal consumed (Amelang and Wettengel 2018: 1).

Other respondents meanwhile focused on the materialities of the solar industry itself, questioning the ethical and justice issues entangled in raw material extraction and manufacturing processes in jurisdictions with weak social and environmental protections (Mulvaney 2013, 2014). As G004 states, "*If you take a broad perspective, you have to question where Germany gets its solar modules from, where are the resources such as copper and raw materials coming from. That has an impact on the countries where these raw materials are excavated, and working conditions for people working in the countries making solar panels are certainly affected … In China, we do not know under what conditions workers manufacture the models*." Sovacool and D'Agostino (2011) for instance note that solar manufacturing costs in China are sometimes kept artificially low by using low-wage labor.

G008 articulated a broader critique of Germany's solar (or any type of renewable energy) transition, drawing attention to the inherent imbalances and inequities built into the global political economy that may inevitably create injustices *somewhere*:

> *Renewable electricity such as solar is underpinned by destructive political economy just like any other industrial processes. Even renewables still destroy the Earth. Which is why you cannot talk about a truly renewable energy transition, you need to also talk about reducing general material throughput, or degrowth. Otherwise, the production of renewable energies relies on the extraction on raw materials and resources around the world. And they are not extracted in socially responsible and environmentally sustainable ways.*

As with macro level injustices highlighted in previous sections, those pertaining to the German PV transition therefore relate strongly to the question marks that hang over the global production chains of mineral extraction, production processes and waste, and the ultimate unevenness built into the system that makes economic activity cheaper in one place compared with another.

4. Discussion: Spatiality and temporality in whole-systems injustices

When taken collectively, our interviews, focus groups, and internet forums identified 44 different injustices. In this section, we assess the spatiality and temporality of these impacts.

4.1 The spatiality of injustices

As predicted by our whole systems approach, justice impacts span spatial scales – from micro, meso, to macro – across the modes of production, manufacturing, consumption, and waste disposal. These are illustrated below in Table 2. Most injustices—19 in total—occur at the micro scale but a compelling number also span the meso scale (11 in total) and the macro scale (14 in total).

Table 2: Summary of spatial scales of injustices for four low-carbon transitions

Case study	*Micro scale injustices*	*Meso scale injustices*	*Macro scale injustices*
French nuclear power	(1) Water consumption, (2) nuclear waste streams, (3) community health, (4) depressed property values, (5) interference with wine making, (6) social peripheralisation and marginalization	(1) Safety, reliability and national accidents (2) Interference with the development of national low-carbon innovations	(1) Accident risks to neighboring countries and beyond (2) Environmental impacts of uranium mining, (3) political impacts of uranium mining, (4) nuclear exports, (5) interference with

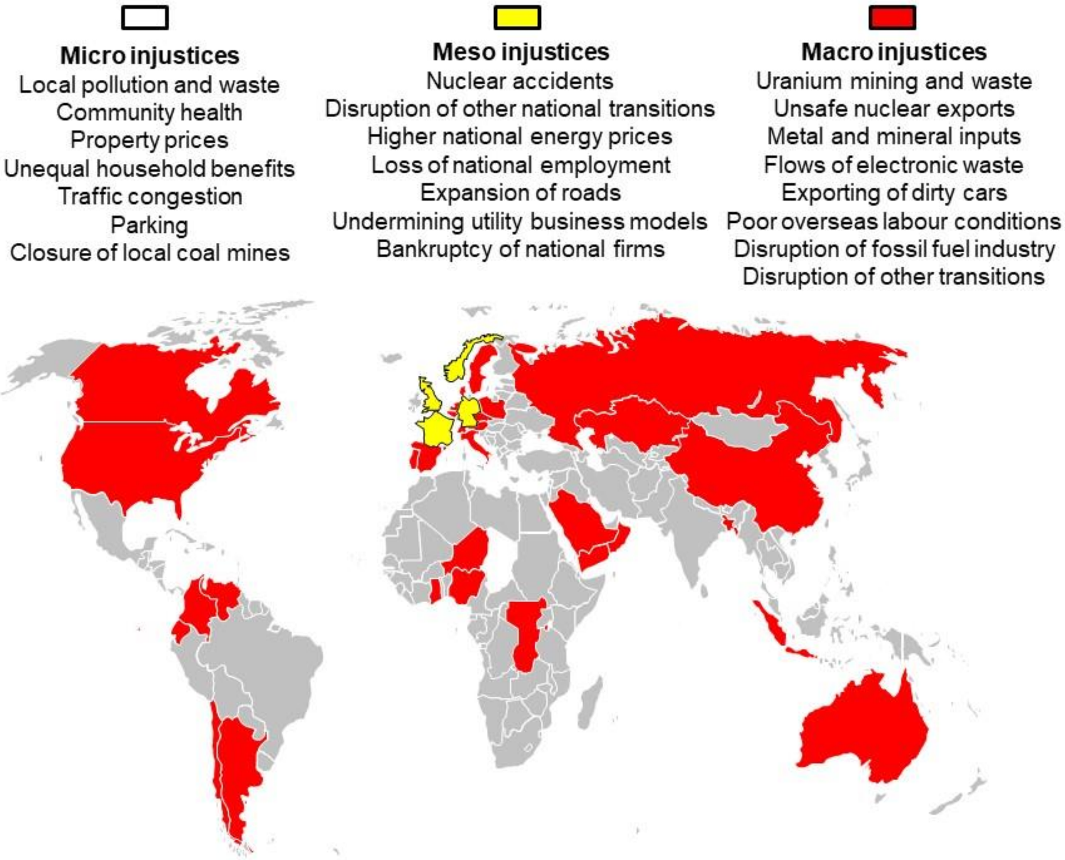
			other European transitions
British smart meters	(7) Exclusion of rural areas, (8) exclusion of those living in social housing blocks (9) rising household energy prices, (10) negative impacts on vulnerable groups, (11) added stress for families	(3) Loss of jobs, (4) higher national energy prices, (5) the environmental impacts of the smart meter roll out	(6) reliance on raw materials from unstable regions, (7) hazardous waste streams
Norwegian electric vehicles	(12) Increased car use leading to congestion, (13) pollution, (14) parking problems, (15) avoidance of walking/cycling, and (16) lack of infrastructure in rural areas	(6) Diversion of taxes from public transport (7) Expansion of roads into environmentally sensitive areas (8) Greenwashing of national policy	(8) Poor labor conditions foreign resource extraction, (9) hazardous waste streams, (10) exporting of dirty cars
German solar panels	(17) Exclusionary nature of the feed-in tariff, (18) local closure of German coal mines (19) Loss of solar manufacturing jobs	(9) Threat to centralized energy supply models, (10) stigmatizing future solar investment and the loss of German solar manufacturing (11) poor employment conditions or standards at German manufacturers	(11) Erosion of markets for electricity in Poland and the Czech Republic (12) disruption of global fossil fuel industries, (13) extraction of raw materials and waste flows, (14) poor working conditions at overseas solar manufacturers

Source: Authors.

Impacts of European energy transitions are thus not limited to or contained by the boundaries of the country undergoing the low-carbon transition, but are interwoven in complex multi-scalar webs of cause and effect. Many of the injustices identified occur at the macro scale well beyond Europe, and effectively amount to a spatial externalization of deleterious environmental and social effects – with the (invariably Northern) countries mainly enjoying positive effects of their low-carbon policies, but invariably Southern countries bearing the costs. Figure 7 maps these out globally, from the lithium mines of South America to the cobalt mines of the Democratic Republic of the Congo, and from the e-waste scrapyards of Ghana to the low-wage manufacturing centers in China. As Bridge et al. (2013:

335) observe, the perverse effect of the gravitation of "clean" energy technology manufacturing to countries such as China has been that this production now takes place largely in "a region with a higher carbon intensity of production." Such a dynamic perpetuates a process of social peripheralisation, whereby proliferating streams of pollution and waste end up in countries that cannot afford to refuse the financial compensation of bearing a high environmental and health risk.

Figure 7: The spatiality of European energy injustices



Source: Authors

In our cases, the French nuclear transition clearly externalizes energy and carbon-intensive processes such as uranium mining, milling, and fuel enrichment to other countries in North America, Asia, Africa and Australasia (Poirson 2012), and our respondents accused France of flooding European neighbors with cheap power that has stymied their own energy transitions. The British smart meter transition has meanwhile generated electronic and hazardous waste streams that could be exported to countries in the Global South (Sovacool et al. 2018), and it also has resulted in carbon emissions related to the fairly inefficient nature of smart meter installations (Holifield et al. 2017). The Norwegian EV transition depends on material inputs such as cobalt, lithium and copper that are produced in areas with weak human and environmental safeguards (e.g. the Democratic Republic of the Congo, see Rustad et al., 2016), and it is also generating waste streams for used batteries and second-hand vehicles (Manzetti, & Mariasiu 2015; Winslow et al. 2018). The German solar transition similarly requires raw materials produced in unstable regions of the world, and depends on low-wage factory workers in countries such as China for manufacturing and assembling modules (Aman et al. 2015).

These extra-territorial dimensions are troubling as they suggest that low-carbon transitions achieve some of their low-carbon or "clean" elements merely by outsourcing injustices (such as "dirty" production) elsewhere (Sovacool 2016). They also illustrate clearly how "energy production, consumption and policy-making decisions in one place can cause hidden but harmful, multi-dimensional, socio-environmental injustices in others" (Healy et al., 2019: 230).

4.2 The temporality of injustices

Another noteworthy dimension to the injustices of low-carbon transitions is their temporality, both in terms of lifecycle impacts as well as the timing of benefits and the inter-generational nature of the negative impacts. Table 3 illustrates injustices distributed across the temporal moments of the technological lifecycle and utilization by consumers. As is evident, 11 injustices were identified at the production stage, 23 at the consumption stage, and 8 at the waste disposal stage.

Table 3: Summary of lifecycle stages of injustices for four low-carbon transitions

Case study	*Production*	*Consumption*	*Waste*
French nuclear power	(1) Water consumption (2) Safety, reliability and accidents (3) Interference with other European low-carbon transitions (4) Environmental impacts of uranium mining (5) Political impacts of uranium mining (6) Nuclear exports	(1) social peripheralisation and marginalization	(1) Nuclear waste streams (2) Community health (3) Depressed property values (4) Interference with wine making

British smart meters	(7) Reliance on raw materials from unstable regions.	(2) Exclusion of rural areas (3) Exclusion of those living in social housing blocks (4) Rising household energy prices (5) Negative impacts on vulnerable groups (6) Added stress for families (7) Loss of jobs (8) Higher national energy prices	(5) Environmental impacts of the smart meter roll out (6) Hazardous waste streams
Norwegian electric vehicles	(8) Poor labor conditions foreign resource extraction.	(9) Increased car use leading to congestion (10) Pollution (11) Parking problems (12) Avoidance of walking/cycling (13) Lack of infrastructure in rural areas (14) Diversion of taxes from public transport (15) Expansion of roads into environmentally sensitive areas (16) Greenwashing of national policy	(7) Hazardous waste streams (8) Exporting of dirty cars
German solar panels	(9) Poor employment conditions or standards at German manufacturers (10) Extraction of raw materials and waste flows, (11) Poor working conditions at overseas solar manufacturers	(17) Exclusionary nature of the feed-in tariff (18) Phasing out of nuclear power plants (19) Local closure of German coal mines (20) Erosion of markets for electricity in Poland and the Czech Republic (21) Undermining of European electric utility business models (22) Stigmatizing future solar investment and the bankruptcy of German solar firms (23) Disruption of global fossil fuel industries,	(10) Extraction of raw materials and waste flows

Source: Authors

In line with a widening focus in the energy justice literature (e.g. Jenkins et al. 2014), the justices identified are dispersed across the lifecycle of low carbon energy transitions. Many of the injustices related to the extraction of minerals that are used in low carbon technology manufacturing and to the disposal of obsolescent materials (Mulvaney 2013; Cross et al. 2018). These also ally with the injustices identified in Table 2 at the “macro” scale, showing how negative impacts on communities are often perceived as being “externalized.” In France’s case the disposal of waste materials within the country means that these impacts are felt closer to home. The majority of injustices however occur however within the consumption phase of the life cycle, in line with other research on low carbon technologies and energy justice (e.g. Sovacool et al. 2017b; Sovacool et al. 2019; Xu and Chen 2019). These relate to injustices generated by various aspects of the rollout of technologies, resulting largely from policy decisions over transition design that inadvertently disadvantage certain social groups or economic actors.

As well as being dispersed across the life-cycle, within the production, consumption, and disposal stages, injustices were also identified across and between generations,. Indeed, inter-generational impacts on future generations were mentioned directly in the interviews, and they are perhaps the starkest for nuclear power, given the long-lived nature of its waste streams (Taebi et al. 2012). As F001 reflected, “*There are clear inter-generational equity issues with nuclear power … And yet we tend to accept these, or ignore them, due to the post war culture of a brave new way forward*". F004 similarly stated that: “*Any discussion of justice must focus on fairness from the perspective of the local territory that will be hosting nuclear facilities. And you must also discuss the fairness towards future generations that will have to deal with that burden*.”

A different temporal dynamic was at work within the British smart meter program—with those adopting first generation (SMETS1) meters suffering from lost functionality if they switched suppliers (see Figure 8), saddling these customers with an inferior technology.

Figure 8: A first generation SMETS1 smart meter from British Gas, London, April 2018

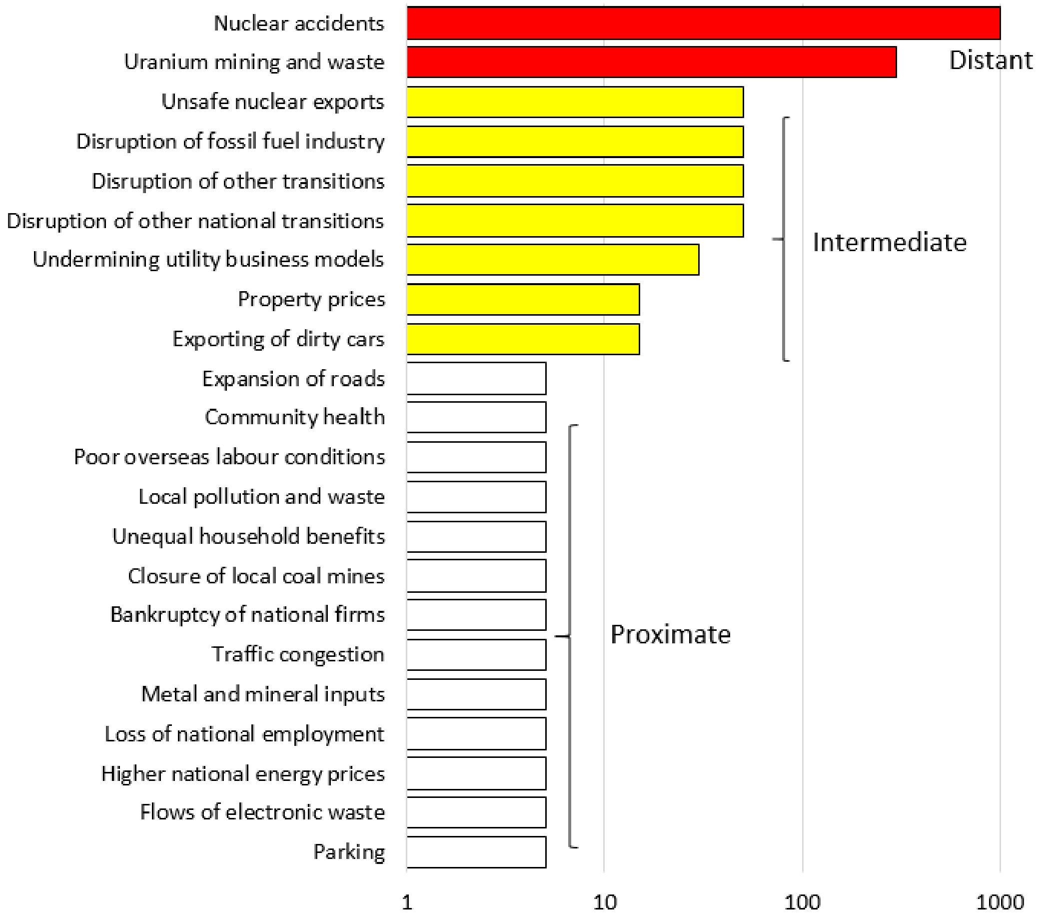
Source: Authors

Norwegian EVs have articulated contrasting temporal dimensions, with early adopters deriving the lion's share of benefits; and later-adopters enjoying fewer and suffering from traffic congestion from the former. As N003 explained: "*The more people that have EV, the fewer the benefits for drivers. You have to take away some of these benefits eventually, everyone cannot be allowed to drive on bus lanes. Once you have too many EVs, they fill up*."

This same dynamic was evident in Germany, with early adopters of solar PV deriving the greatest benefits. As a respondent in our focus group iterated: "*The German feed-in tariff for solar was more profitable 18 years ago, but not now*."

Consequently, the injustices have different temporal dynamics in how, or more precisely *when*, they are experienced. Figure 9 shows that some proximate impacts are more immediate, they are experienced already, in the "now," or soon, generally within the next five years. This includes many injustices such as parking and traffic congestion (for EVs), flows of e-waste and fuel poverty (for smart meters), local pollution and community health (French nuclear), and closure of coal mines and rising costs with the feed-in tariff (German solar energy). However, other injustices will be experienced more intermediately in the future, roughly in the next ten to fifty years. This would include the future displacement of fossil fuel or "dirty" cars from Norway to other countries as they are substituted by EVs, or a future decline in property prices that could result from new French nuclear power plants, or further incidents and accidents. The impacts of national and transnational disruption of future energy transitions would also occur on this scale, as well as the continued exportation of technology from Europe abroad and continual instability on fossil fuel business models. A very particular set of injustices are extremely distant or long-lived, extending well into the future. This includes temporal injustice that could span hundreds of years to even 1000 years, such as the need to manage radioactive waste and mine tailings, or to recover from the fallout of severe nuclear accidents.

Figure 9: The proximate, intermediate, and distant temporalities of energy injustices



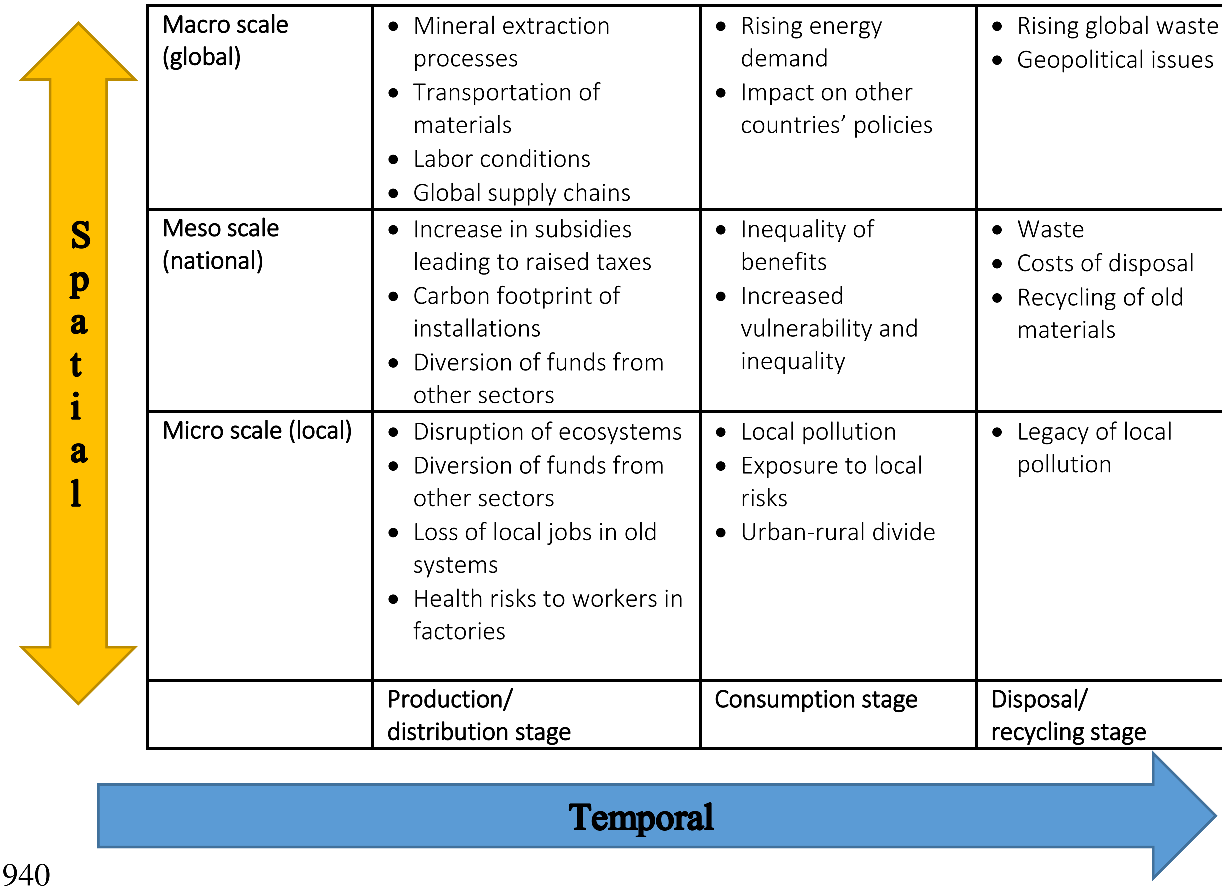
Source: Authors

5. Conclusion and Implications

In sum, the whole systems energy justice analysis presented here demands we better understand, account for, and attempt to minimize the ways in which European (and other) low-carbon transitions can give rise to, and then systematize, injustices – across social segments, spatial scales, and temporalities.

The injustices associated with European low-carbon transitions—summarized in Figure 10—transcend scales (micro, meso, macro) and lifecycle stages (of production and distribution, consumption, and waste disposal and recycling). In this way, a French restaurant using nuclear electricity to bake croissants connects with a worker inhaling toxic fumes at a uranium mine in Niger or Canada, from where nearly half of France's uranium imports come from. A British household using their smart meter and in-home display to monitor their laundry is generating electronic waste that could end up in the fields and farms of Ghana. A parent picking up their children from school in an electric vehicle in Norway depends in part on the backbreaking labor of mineral extraction across lithium and cobalt mines in the Democratic Republic of the Congo. A German solar panel supporting a pensioner's retirement in Berlin may have been manufactured at a low-wage factory in China.

Figure 10: Whole systems energy justice impacts of European low-carbon transitions



Macro scale (global)	• Mineral extraction processes • Transportation of materials • Labor conditions • Global supply chains	• Rising energy demand • Impact on other countries' policies	• Rising global waste • Geopolitical issues
Meso scale (national)	• Increase in subsidies leading to raised taxes • Carbon footprint of installations • Diversion of funds from other sectors	• Inequality of benefits • Increased vulnerability and inequality	• Waste • Costs of disposal • Recycling of old materials
Micro scale (local)	• Disruption of ecosystems • Diversion of funds from other sectors • Loss of local jobs in old systems • Health risks to workers in factories	• Local pollution • Exposure to local risks • Urban-rural divide	• Legacy of local pollution
	Production/ distribution stage	**Consumption stage**	**Disposal/ recycling stage**

However, Figure 10 also reveals some of the limitations to a "whole systems" approach, insofar as the micro, meso, and macro scales do not always map evenly or systematically onto the different lifecycle stages of each low-carbon transition, and vice versa. Instead, the interactions between scales and stages is dynamic and more heterogeneous than the analytical categories themselves imply. For instance, we identified issues such as waste and water pollution with French nuclear power as “micro” concerns, as they affect local communities the most directly, but in aggregate those aspects could become serious national concerns over time. We identified increased carbon emissions from the inefficient, supplier-led smart meter rollout as “meso” concerns, affecting the national carbon balance, but emissions from installation vehicles could also contribute to local particle pollution (“micro”) and contribute to global warming (“macro”). We classified unequal and elitist tax policy in Norway as “meso,” a nationwide issue, even though it intersects strongly with ‘micro’ household dynamics; inversely, we classified unequal access to solar energy in Germany as ‘micro’, for affecting households, even though this inequality is embedded in national policy.

Moreover, these injustices are inherently relational and may be experienced differently by different people in different places at distinct times, and sometimes negative impacts can be unexpected or unintended. For instance, what some perceive as an injustice or direct and severe harm may be experienced by others as a mere nuisance or inconvenience, and vice versa. Thus, as Castán-Broto and Baker (2018: 3) argue, “energy is bound up with the reproduction of uneven patterns of development and access” that are not “pre-existing, fixed” categories, but are “actively constituted through social and material relations.” Some identified injustices, such as nuclear waste or the fallout from a nuclear accident, could last hundreds of years to millennia; others such as unemployment or traffic congestion, could be more transient and temporary.

In terms of concrete policy recommendations, our study does point towards a multitude of actions that planners can take at any of the scales we examine. At the “micro” scale, local content requirements or benefit-sharing agreements (demanding that project or technology developers use local materials and labor and/or share more benefits with communities) can help address some of the distributive inequalities that arise related to displacement and unemployment. Similarly, such actions could improve the legitimacy of the transition in the eyes of affected parties and culminate in a broader social license to operate. At the “meso” scale, planners and parliamentarians could hold public referendums on the transition in question, to solicit public feedback about concerns, and erect statutes that better track or account for embodied emissions and lifecycle impacts. At the “macro” scale, groups like the International Energy Agency, International Renewable Energy Agency, and Intergovernmental Panel on Climate Change are well positioned to recognize and account for embodied global externalities, e.g. carbon, water, and land use but also perhaps waste, toxic pollution, and metals—across different energy systems. Moreover, improved transparency about raw materials and waste streams would be beneficial, just as the Extractive Industries Transparency Initiative has attempted in the oil and gas sector, or the World Commission on Dams has done in the hydropower sector. Furthermore, the longevity and often complicated legacy of energy transitions indicates a need for whole systems thinking at the technical and policy *design* stage, when they consider policy processes and responses to transitions.

We do not believe our findings undermine the overarching rationale for low-carbon transitions, nor do they suggest that the four specific transitions we examined should have been abandoned. However, based on our findings, and new theorizations of whole systems energy injustice, planners, policymakers, practitioners, and researchers should nonetheless become more cognizant of the potential for low-carbon transitions to create new – and worsen preexisting – patterns of exploitation and inequality. The specific critiques we raise, some of them sobering, are aimed at a target: improving and learning so that vulnerability in low-carbon transitions is minimized, benefits and burdens are made more visible, and the potential gains are distributed more fairly and according to representative processes. Dealing with the spatial and temporal whole systems nature of energy justice is thus as necessary as it is demanding.

6. References

Alberini, Anna, Andrea Bigano, Milan Ščasný, Iva Zvěřinová, Preferences for Energy Efficiency vs. Renewables: What Is the Willingness to Pay to Reduce CO2 Emissions?, *Ecological Economics*, Volume 144, February 2018, Pages 171-185

Alexander, C. and Reno, J. eds., 2012. *Economies of Recycling: the global transformation of materials, values and social relations*. Zed Books Ltd..

Aman, M.M., Solangi, K.H., Hossain, M.S., Badarudin, A., Jasmon, G.B., Mokhlis, H., Bakar, A.H.A. and Kazi, S.N., 2015. A review of Safety, Health and Environmental (SHE) issues of solar energy system. *Renewable and Sustainable Energy Reviews*, *41*, pp.1190-1204.

Amelang, Sören and Julian Wettengel. Germany's dependence on imported fossil fuels. March 8. Available at https://www.cleanenergywire.org/factsheets/germanys-dependence-imported-fossil-fuels

Anarow, B., Greener, C., Gupta, V., Kinsley, M., Henderson, J., Page, C., & Parrot, K. (2003). Whole-Systems framework for sustainable consumption and production, Vol. 807. Denmark: Danish Ministry of the Environment, pp. 1-51.

Araújo, K. Low Carbon Energy Transitions: Turning Points in National Policy and Innovation 2017, Oxford, UK: Oxford University Press.

Balbus, John M., Jeffery B. Greenblatt , Ramya Chari , Dev Millstein & Kristie L. Ebi, A wedge-based approach to estimating health co-benefits of climate change mitigation activities in the United States. *Climatic Change,* November 2014, Volume 127, Issue 2, pp 199-210.

Bickerstaff, K., Walker, G. and Bulkeley, H. eds., 2013. *Energy justice in a changing climate: social equity and low-carbon energy*. Zed Books Ltd.

Bouzarovski, S. and Simcock, N., 2017. Spatializing energy justice. *Energy Policy*, *107*, pp.640-648.

Bridge, G., Bouzarovski, S., Bradshaw, M., & Eyre, N. (2013). Geographies of energy transition: Space, place and the low-carbon economy. Energy Policy, 53, 331–340.

Bridge, G., Barca, S., Özkaynak, B., Turhan, E. and Wyeth, R., 2018a. Towards a Political Ecology of EU Energy Policy. In *Advancing Energy Policy* (pp. 163-175). Palgrave Pivot, Cham.

Bridge, G., Barr, S., Bouzarovski, S., Bradshaw, M., Brown, E., Bulkeley, H. and Walker, G., 2018b. *Energy and Society: A Critical Perspective*. Routledge.

Bridge, G., Özkaynak, B. and Turhan, E., 2018c. Energy infrastructure and the fate of the nation: introduction to special issue. *Energy Research & Social Science*.

Castán-Broto, Vanesa and Lucy Baker, Spatial adventures in energy studies: An introduction to the special issue, Energy Research & Social Science, Volume 36, 2018, Pages 1-10,

Burke, Marshall et al., Large potential reduction in economic damages under UN mitigation targets, Nature 557 (May 24, 2018), pp. 549-553.

Canzler, Weert, Franziska Engels, Jan-Christoph Rogge, Dagmar Simon, Alexander Wentland, From "living lab" to strategic action field: Bringing together energy, mobility, and Information Technology in Germany, Energy Research & Social Science, Volume 27, May 2017, Pages 25-35

Charnley, Fiona, Mark Lemon, Steve Evans, Exploring the process of whole system design, Design Studies, Volume 32, Issue 2, March 2011, Pages 156-179

Coenen, L., Benneworth, P., & Truffer, B. (2012). Toward a spatial perspective on sustainability transitions. Research Policy, 41(6), 968–979.

Cross, Jamie and Declan Murray, The afterlives of solar power: Waste and repair off the grid in Kenya, Energy Research & Social Science 44 (2018) 100–109

Dominish, Elsa, Chris Briggs, Sven Teske, and Franziska Mey. 2019. Just Transition: Employment Projections for the 2.0 °C and 1.5 °C Scenarios. In S. Teske (ed.), Achieving the Paris Climate Agreement Goals (London: Springer), pp. 413-435.

Dopfer, Kurt, John Foster, and Jason Potts. Micro–meso–macro. J Evol Econ (2004) 14: 263–279.

Fuller, S. and McCauley, D., 2016. Framing energy justice: perspectives from activism and advocacy. *Energy Research & Social Science*, *11*, pp.1-8.

German Federal Ministry for Economic Affairs and Energy. 2017. Renewable Energy Sources in Figures National and International Development, 2016. September. Berlin.

Healy, Noel and John Barry. 2017. Politicizing energy justice and energy system transitions: Fossil fuel divestment and a "just transition". Energy Policy 108 (2017) 451–459

Healy, N., Stephens, J. C., & Malin, S. A. (2019). Embodied energy injustices: Unveiling and politicizing the transboundary harms of fossil fuel extractivism and fossil fuel supply chains. Energy Research & Social Science, 48 (June 2018), 219–234.

Heffron, R. (2018). The application of distributive justice to energy taxation utilising sovereign wealth funds. Energy Policy, Volume 122, November 2018, Pages 649-654.

Heffron, Raphael J. and Darren McCauley. 2018. What is the 'Just Transition'? Geoforum 88, pp. 74–77

Hiteva, R and BK Sovacool. "Harnessing Social Innovation for Energy Justice: A Business Model Perspective," Energy Policy 107 (August, 2017), pp. 631-639.

Holifield, R., Chakraborty, J. and Walker, G. eds., 2017. *The Routledge handbook of environmental justice*. Routledge.

House of Commons Science and Technology Committee, 2016. Evidence check: smart metering of electricity and gas, September 24

International Energy Agency. 2018. Nordic EV Outlook 2018: Insights from leaders in electric mobility (Paris: OECD).

IRSN. 2014. Incident à la centrale de Fessenheim. February 20. https://www.irsn.fr/FR/Actualites_presse/Communiques_et_dossiers_de_presse/Pages/incident_centrale_Fessenheim.aspx#.W-L9RJP7TIU

Jamison, A. and Baark, E. Technological Innovation and Environmental Concern: Contending Policy Models in China and Vietnam. Discussion Paper No. 1987. Lund, Sweden: Research Policy Studies, . Research Policy Institute. ; 1990

Jenkins, K, D. McCauley, R.J. Heffron, H. Stephan, Energy justice, a whole systems approach, Queen's Polit. Rev. 29 (2) (2014) 74–87.

Jenkins, Kirsten, Darren McCauley, Raphael Heffron, Hannes Stephan, and Robert Rehner. 2016. Energy justice: A conceptual review, Energy Research & Social Science, Volume 11, January 2016, Pages 174-182

Jenkins, KEH, D. McCauley, A. Forman, Energy justice: a policy approach, Energy Policy 105 (2017) 631–634.

Jenkins, KEH. 2018. Setting energy justice apart from the crowd: Lessons from environmental and climate justice. Energy Research & Social Science 39 (2018) 117–121

Johnstone, P. and Kivimaa, P., 2018. Multiple dimensions of disruption, energy transitions and industrial policy. *Energy Research & Social Science*, *37*, pp.260-265.

Kapiriri, Lydia, Ole Frithjof Norheim, Douglas K. Martin, Priority setting at the micro-, meso- and macro-levels in Canada, Norway and Uganda, Health Policy, Volume 82, Issue 1, 2007, Pages 78-94

Kass, M.J., 2018. The End of the Road for Gas-Powered Automobiles?. *Natural Resources & Environment*, *32*(4), pp.53-54.

Liljenstrom, Hans and Uno Svedin. Micro, Meso, Macro: Addressing Complex Systems Couplings. Singapore: World Scientific, 2005.

Manzetti, S. and Mariasiu, F., 2015. Electric vehicle battery technologies: From present state to future systems. *Renewable and Sustainable Energy Reviews*, *51*, pp.1004-1012.

Mclaren, D. P. (2012). Justice and low carbon energy transitions, A review and synthesis of work undertaken by InCluESEV, (March).

McCauley, D, et al. 2019. “Energy justice in the transition to low carbon energy systems: Exploring key themes in interdisciplinary research,” Applied Energy 233 (January), pp. 916-921

Meckling, J. and Hughes, L., 2018. Protecting Solar: Global Supply Chains and Business Power. *New Political Economy*, *23*(1), pp.88-104.

Mulvaney, D. (2013). Opening the Black Box of Solar Energy Technologies: Exploring Tensions Between Innovation and Environmental Justice. Science As Culture, 22(3), 214¬–221

Mulvaney, D. (2014) ‘Are Green Jobs Just Jobs? Cadmium Narratives in the Life Cycle of Photovoltaics’, Geoforum, 54, 178–186

Noel, L, G Zarazua de Rubens, and BK Sovacool. “Optimizing innovation, carbon and health in transport: Assessing socially optimal electric mobility and vehicle-to-grid (V2G) pathways in Denmark,” Energy 153 (June, 2018), pp. 628-637.

Noel, L., de Rubens, G.Z., Sovacool, B.K. and Kester, J., 2019. Fear and loathing of electric vehicles: The reactionary rhetoric of range anxiety. *Energy Research & Social Science*, *48*, pp.96-107.

OIV 2018. State of the Vitiviniculture World Market, April 2018. International Organisation of Vine and Wine. Online: http://www.oiv.int/public/medias/5958/oiv-state-of-the-vitiviniculture-world-market-april-2018.pdf [Accessed 30.10.2018]

Pickren, G., 2014. Geographies of E-waste: Towards a Political Ecology Approach to E-waste and Digital Technologies. *Geography Compass*, *8*(2), pp.111-124.

Poirson, Juliette. 2012. Areva in Africa; the hidden face of French nuclear power. WISE Nuclear Monitor Issue 750(4244), June 1. Available at https://www.wiseinternational.org/nuclear-monitor/750/areva-africa-hidden-face-french-nuclear-power.

Raven, R., Schot, J., & Berkhout, F. (2012). Space and scale in socio-technical transitions. Environmental Innovation and Societal Transitions, 4, 63–78.

Rustad, S. A., Østby, G., & Nordås, R. (2016). Artisanal mining, conflict, and sexual violence in Eastern DRC. The Extractive Industries and Society, 3(2), 475–484.

Seiffert, M., & Loch, C. (2005). Systemic thinking in environmental management: support for sustainable development. Journal of Cleaner Production, 13, 1197-1202

Sovacool, BK and AL D'Agostino. Summoning the Sun: Evaluating China's Renewable Energy Development Project (REDP) (Singapore: Lee Kuan Yew School of Public Policy Energy Governance Case Study #06, May, 2011), 25 pp.

Sovacool, BK. "What Are We Doing Here? Analyzing Fifteen Years of Energy Scholarship and Proposing a Social Science Research Agenda," Energy Research & Social Science 1 (March, 2014), pp. 1-29.

Sovacool, B.K., 2016. The political ecology and justice of energy. In *The Palgrave Handbook of the International Political Economy of Energy* (pp. 529-558). Palgrave Macmillan, London.

Sovacool, BK and MH Dworkin. Global Energy Justice: Problems, Principles, and Practices (Cambridge: Cambridge University Press, 2014).

Sovacool, BK and MH Dworkin. "Energy Justice: Conceptual Insights and Practical Applications," Applied Energy 142 (March 15, 2015), pp. 435-444.

Sovacool, BK, M Burke, L Baker, CK Kotikalapudi, and H Wlokas. 2017a. "New frontiers and conceptual frameworks for energy justice," Energy Policy 105 (June, 2017), pp. 677-69

Sovacool, BK, P Kivimaa, S Hielscher, and K Jenkins. 2017b. “Vulnerability and resistance in the United Kingdom’s smart meter transition,” Energy Policy 109 (October, 2017), pp. 767-78.

Sovacool, BK, P Kivimaa, and K Jenkins. The smart meter rollout: Social questions and challenges (Brighton, UK: Centre on Innovation and Energy Demand, Policy Briefing 8, January, 2018), 4pp.

Sovacool, Benjamin K., et al. 2019. "Energy injustice and Nordic electric mobility: Inequality, elitism, and externalities in the electrification of vehicle-to-grid (V2G) transport." Ecological Economics 157, 205-217

Stansinoupolos, P., Smith, M.H., Hargroves, K. and Desha, C., 2013. *Whole system design: An integrated approach to sustainable engineering*. Routledge.

Taebi, B., Roeser, S. and van de Poel, I., 2012. The ethics of nuclear power: Social experiments, intergenerational justice, and emotions. *Energy Policy*, *51*, pp.202-206.

Ürge-Vorsatz, Diana et al. 2014. Measuring the Co-Benefits of Climate Change Mitigation Annual Review of Environment and Resources, Vol. 39:549-582.

Wheatley, S, BK Sovacool, and D Sornette. “Of Disasters and Dragon Kings: A Statistical Analysis of Nuclear Power Incidents & Accidents,” Risk Analysis 37(1) (January, 2017), pp. 99-115

Winslow, K.M., Laux, S.J. and Townsend, T.G., 2018. A review on the growing concern and potential management strategies of waste lithium-ion batteries. *Resources, Conservation and Recycling*, *129*, pp.263-277.

Wittenberg, Inga, Ellen Matthies, Solar policy and practice in Germany: How do residential households with solar panels use electricity?, Energy Research & Social Science, Volume 21, 2016, Pages 199-211

World Nuclear Association. Nuclear Power in France. 2018. September. Available at http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/france.aspx

Xu, Xiaojing and Chien-fei Chen. 2019. Energy efficiency and energy justice for U.S. low-income households: An analysis of multifaceted challenges and potential. Energy Policy 128. 763–774