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The Effect Of Shocks On Sustainability Transitions

Phil Johnstone and Johan Schot

Abstract

The role of exogenous shocks in influencing transition process is of significant interest to diverse literatures in Sustainability Science. Such events disturb and interrupt path dependent processes in ecological, economic, social, and technological systems. Sometimes this can lead to radical departures from existing trajectories and at other times existing systems can be more resilient, adapting or reconfiguring in response to a shock. In this paper we explore the role that exogenous shocks can have on meso-level developments. We utilise the Multi-Level Perspective (MLP) to compare two archetypal exogenous shocks, World War II and the 1973 Oil crisis, and examine the effects these events had on the evolution of the transatlantic energy system. We build a framework from MLP literatures for addressing the role of shocks based around the dimensions of the timing dynamics of the shock, and directionality drawing on the contrasting perspectives of windows of opportunity and imprinting theories. We examine two illustrative case studies that were formative exogenous events in the evolution of the transatlantic energy system: World War II and the 1973 oil crisis. We compare and contrast these two exogenous shocks and make propositions around the degree to which they exhibit dynamics of imprinting or windows of opportunity. We elucidate the different effects shocks can have, and the different mechanisms that can play a role in change processes following a shock with implications for prospective sustainability transitions.

1. Introduction: sustainability in a time of perpetual crises?

We live in an age of perpetual crisis. These were the words of British journalist Andy Beckett in a long-read in the Guardian. The date of that article is remarkable: 17th December, 2019 (1). One did not have to wait long to see a once in a lifetime global pandemic that uprooted every facet of society, and a subsequent new war in the heart of Europe: the invasion of Ukraine by Russia leading to an energy crisis. We live during a time where we are often told, “the world will never be the same” (2). These are stark examples of what are labelled exogenous shocks recognised in Sustainability Science (SS) as important for understanding sustainable development. Shocks cover natural disasters, industrial disasters, environmental tipping points as well as climate change (3). The research question of this article is how to conceptualize the role of such exogenous events in sustainability transitions?

To answer this question we mobilise the Multi-Level Perspective (MLP). Here exogenous shocks are disruptions or rupture points in the timelines of the path-dependent evolution of a socio-technical system, and for varying degrees of time, ensure that a system is exposed to a set of contextual conditions that differ from normal path-dependent conditions. This definition is aligned with general social science institutional analysis (4). In the MLP sociotechnical systems contain different (more or less) aligned dimensions (sometimes called sub-systems) including science, technology and infrastructures, industry strategy and networks, policy, politics and governance, markets and user preferences, and cultural perceptions and symbols (5). Following Clark et al., (in this issue) we see these systems as similar to production-consumption systems as analysed in the SS literature.

Following the MLP we emphasize that these systems are expressions of rules or institutions used by actors to guide and shape their behaviour. The total rule-set is called a regime and actors using them are called regime actors. Central to MLP is the idea that some actors may decide not to follow dominant rules and develop alternative practices in niches. The MLP focuses on sustainability

transitions occurring as a result of interactions between niches (micro level), regimes (rule-sets) expressed in socio-technical systems (meso level) and landscape developments, including shocks and trends (macro level). Stability is located at the level of the regime through the formation of rules which can be understood as institutions, both informal and formal which guide and shape action and create path dependencies entailing inertia making regimes and systems difficult to change. Niches are incubators of new systems and regimes, and struggle to diffuse more widely because of path dependence at the regime and system level.

We seek answers to our research question by exploring how shocks (operating at the landscape level) influence change in sociotechnical systems and regime, and niche-regime dynamics. This is an important topic not only because in coming decades shocks are expected to happen more often due to the climate and biodiversity crisis, growing inequalities, and the implicated growing potential for wars, but also because exogenous shocks can rapidly interrupt inert path dependencies of regimes and contain the opportunity for system change (towards sustainability) to occur more rapidly. The role of shocks is not well conceptualized, and understanding shocks is of notable interest to diverse SS literatures including for example, environmental economics (6), socio-ecological systems and resilience (7), and environmental governance (8).

Rather than discuss differences between these diverse contributions to the SS literature, more important is to illustrate commonalities: a given focal entity be it a system, a sector, or a policy regime, develops in incremental and path-dependent ways, where particular processes become routine and overtime garner momentum making such a focal entity difficult to change. Across these literatures a shock is something that is external to the dynamics of the focal entity and rapidly brings about a different set of conditions that can lead to pressure being exerted on the focal entity in question. These diverse perspectives recognise shocks and uncertainty as a source of branching points where alternative trajectories become possible (3).

In this article we thus put the shocks themselves centre stage. We first discuss how the effects shocks have been understood in the MLP literature in terms of windows of opportunity, typologies of transition pathways, and theories of imprinting leading to a fresh and novel understanding of the role of shocks in which shocks are not just exogenous events. We then discuss our methods, before conducting an analysis of two case studies of archetypal shock events in the development of energy systems: World War II and the 1973 oil crisis. We offer an analysis of these shocks to illustrate and explore the usefulness of our framework for sustainability science.

2. Exogenous shocks and the MLP: timing, dynamics, and directionality

A main way in which the effects of landscape shocks have been characterised in the MLP literature is as windows of opportunity. Indeed, it often appears in the description accompanying the figure depicting the MLP heuristic that ***"landscape developments put pressure on the existing system, which opens up, creating 'windows of opportunity' for niche innovations"*** (see for example Geels et al (9, p.466)). In such moments the role of actors (such as policy makers or civil society) is important. In the MLP it is argued that actors in niches and regimes cannot directly influence what is happening at the landscape macro environment, yet how the landscape is impacting on the regime-niche dynamics is shaped by how actors interpret landscape developments and translate their interpretations into action. Thus, to take one key example, MLP accounts of the landscape shock of the Fukushima nuclear disaster have focussed on how it shaped the development of energy systems across national settings in a very different way subject to diverse responses by policy actors and the different ways in which the disaster was represented (10), or the construction of differing narratives of the Fukushima disaster (11).

Such a windows of opportunity approach often draws on Kingdon's policy streams (12) where exogenous shocks can be moments where environmental, policy, and political processes towards a particular goal

can converge and 'policy entrepreneurs' can have a rare opportunity to alter dominant trajectories even discontinuing certain unsustainable technological pathways (13). The perspective of critical junctures has been drawn on to examine the ways that politics and policy can accelerate transitions following a shock event that weakens incumbent regimes (14). A critical juncture is not automatically critical but becomes so if policy decisions following an exogenous shock are implemented that lead to new forms of path dependency or reinforce prior dynamics closing down the opportunity for change (15). The role of changing political coalitions following a shock and how political coalitions can utilise momentary disruptions in existing path dependencies to influence change has been another focus (16). Despite differences, these perspectives focus on the role of shocks in terms of decisions taken by actors in response to a shock and how competing agents of change including policy makers, NGOs, and industrial interests utilise these moments to accelerate transitions through supporting new niche developments or protect existing interests from those competing interests in times of crisis.

While interpretation by actors is key, the context in which this interpretation takes place is important too. Much depends on the issue of timing. The question of timing is understood in the MLP in terms of the stage of transition dynamics. A crucial question is the extent to which niche-based innovations and rules (institutions) are mature and stable. In addition to timing, the intensity of the exogenous shock matters. Geels & Schot (5, 17) have outlined a typology of transitions pathways and make propositions around the different effects landscape shocks will have taking into account both timing and intensity of the stock. They highlight that if sociotechnical niches are not fully developed at the time of a shock and it is of moderate intensity only affecting a limited number of system dimensions then a shock event may not lead to significant system change. Rather, system modification may occur where regime actors "use their adaptive capacities to reorient development trajectories" (17, p.407). On the other hand, if niches are mature and well developed and a shock is powerful then niches may break through and lead to a replacement of the dominant system (this is what they call a substitution pathway). Other options include a de-alignment and re-alignment pathway where shocks are strong and destabilise systems (they are not perceived as viable anymore), while no alternatives exist, leading to the emergence of competing niches, and finally a re-configuration pathway where niches are integrated in a changing system configuration and shocks encourage this process, but are not decisive.

There is nothing causal or inevitable about these different pathways, they are ideal typical, however can offer a useful analysis for assessing why actors take up the windows of opportunity offered by a shock. However, shocks are not just windows of opportunity. They are also traumatic events whose impact can be pervasive and deep going beyond a more rational interpretation of threats and opportunities provided by a shock. This type of impact has been neglected in MLP. Building on the Deep Transition perspective (18) Johnstone & McLeish (19, 20) and McLeish et al (21) have developed this idea by introducing the notion of imprinting utilised in biology, psychology, and organisational studies. Imprinting places primary focus on the mechanism that cause features of the shock are "stamped in during a brief sensitive period" (22). In MLP terms this is understood as how imprinting impacts directly, deeply and suddenly the set of rules actors used to guide their behaviour and where these rules remain in place after the sensitive period has ended (21). Johnstone and McLeish have identified four mechanisms that shape the imprinting process: demand pressures, directionality, new policy capacities, shared sacrifice and cooperation (19)[1].

1. Demand pressures and logistical challenges refer to the dynamics affecting supply and consumption that differ from normal path dependent conditions. For example, in world wars the energy system faced a key challenge of maintaining supply as demand increased from the military; during the first Covid lockdown the demand pressure was different in term of an unprecedented reduction in demand; directionality refers to how shocks can rapidly alter regime and niche configurations as the energy system becomes oriented around the challenges of dealing with new demand pressures; new policy capacities examines how the new conditions of shocks provoke new policy capacities that can influence change; shared sacrifice and collaboration focusses on how new ways of working together across society and between different actors often appear in emergency situations and can be a motivator for change (19, 20, 60).

Thus, we can see two complementary lenses for understanding shocks. Landscape shocks interrupt the path dependent evolution of rules in a regime through creating a new selection environment in which regime and niche actors operate. Regime and niche actors may interpret such a shock as a window of opportunity and use it to strengthen niche development and de-stabilise dominant systems. Whether this happens is dependent on timing. Landscape shocks may also have a more forceful immediate impact on behaviour and rules guiding niche and regime actors by putting in place new rules. Whether this happens is dependent on the four mechanisms mentioned above.

Based on an analysis focussed on these different aspects and through a comparative analysis of World War II and the 1973 oil crisis and their impact on transatlantic energy systems, we explore the extent to which processes of imprinting or a window of opportunity emerged following each shock. We then make propositions about the different mechanisms of change of imprinting and window of opportunity and under what conditions (timing and dynamics of shock) they may contribute to a sustainability transition.

3. Framework and methodological approach

We conduct a comparative analysis focus on two case studies of landscape shocks: World War II and the Oil Crisis of 1973. These two cases represent punctuations in the timeline of the development of the transatlantic energy system. The transatlantic energy system is the focal entity we are examining. The two case studies are a good fit because it is widely recognised in energy literatures that these two events had a significant impact on the development of transatlantic energy systems (23, 24) and regularly cited as examples of landscape shocks in the MLP (25, 26). However, in accounts using a MLP analysis, it often remains the case that these shocks are mentioned in passing, rather than a careful analysis of how their dynamics and effects differ. We do not focus on comparing national developments, instead we use the notion of a zone. This is an area of deep transnational exchanges and institutional connections that is affected in a similar ways by a shock. A zone contains nation-states that share vulnerabilities, they read each other's experiences and policy responses. The borders of a zone could be fuzzy as connections and sharing experiences may not respect specific national borders. The result of this spatial focus is that we try to identify commonalities, while occasionally paying attention to national specificities within the generic pattern (Rodgers 1998, Barry 2001).

To understand the effects of landscape shocks on the transatlantic energy system we characterise the energy system prior to the beginning of the exogenous shock in terms of niche-regime dynamics and rules. Then we focus on what developments that occurred during the shock paying attention to the mechanisms of the shock period and show how they influenced various system dimensions as well as what rules were amplified during the shock period. Finally, we analyse subsequent changes in directionality of the energy system, here we focus on the extent to which system dimensions or rules that were amplified or changed during the shock persisted. Throughout we are attentive to whether we see actors responding to the window of opportunity by acting on one or more system dimensions, or whether the rules they use to guide their behaviour are changed due to imprinting (see table 1 for guiding questions and concepts). Our analysis relies on a wide variety of literature from energy studies, political economy, and history to construct a plausible interpretive account. Our initial literature research focussed on identifying literatures that were focussed on a long and broad interpretation of energy systems that encapsulated the transatlantic zone (27–29). We used a snowballing strategy to gather further relevant data that was useful for the interpretive task.

Table 1: Questions and concepts used in the analysis of impact of shocks on transitions

	Question	Concepts and evidence
1. Timing	What was the characteristics of the transatlantic energy regime prior to the shock? How stable was the regime? How mature were niche developments?	Assessing how the transatlantic energy system characterised in diverse literatures. Examining relevant evidence of regime stability/ instability; Examining evidence of maturity of niches
2. Shock dynamics	How was the transatlantic energy system developing in terms of sociotechnical system changes and change of rules?	Assessing how the energy system was affected by mechanisms of crisis in terms of demand pressures, directionality, new policy capacities; shared sacrifice; Assessing how system dimensions and rules changed during this period
3. Directionality	How did the shock influence subsequent developments in the energy system?	Assessing the extent to which rules introduced or amplified during the shock persisted, and whether there was convergence and stability across the transatlantic zone?

4. Analysis: the role of shocks in the evolution of transatlantic energy systems

4.1. World War II

4.1.1 Timing

In the years between WWI and WWII, the transatlantic energy system was fraught with competition and divergences in terms of technological trajectories and rules (19, 30). The energy system varied considerably between the USA and Europe in terms of the extent to which oil was used. Broad trends are characterised in the literature which we now summarise:

- Oil represented a mature niche that was competing directly against what is identified as the incumbent coal regime (31). Oil's share in the energy mix had risen steadily in the with the diffusion of automobiles and associated infrastructure compared to the persistence of steam powered rail travel in Europe. Prior to WWII the share of oil in total primary energy consumption in Western Europe was 10% while in the USA it was 30% (32).
- Another key trend identified is increasing electrification with competition between different paradigms of electricity production between localised independent grids, and increasingly integrated centralised national grids with grids remaining more fragmented than integrated at the start of the war (33–35).
- This period saw instability regards to institutions surrounding the energy system, with competition and divergence in terms of the international control of oil which was a key factor in different strategies in the build up to the conflict which each nation perusing strategies to access oil deemed essential for military endeavours (36). There was significant debate regarding the appropriate levels of state intervention and regulation in energy as opposed to private ownership and more liberalised energy sector with variances in the extent of state intervention across the transatlantic zone (33).

Table 2: Overview of transatlantic energy system before WWII

Focus	Summary
Niche	Niches at a mature stage and pressuring the regime; oil in direct competition with dominant coal regime. Lack of institutional stability with regards to international supply of oil with competing interests for control over resources in Middle East. In Europe, slow growth of oil and automobile use.
Regime	Coal still largest share of energy in transatlantic zone. Declining share of coal in USA; coal remains dominant in uses including heating and transportation in Europe. Electricity systems still dominated by disparate local electricity grids.

4.1.2 Shock dynamics and WWII

WWII was a 'total war' where entire populations were geared towards the singular aim of victory, rather than just dedicated militaries (37). As a consequence, every aspect of society and economy were affected. The mechanisms of this shock influenced all dimensions of the energy system in profound ways. As such, the effects of the shock can be considered as an avalanche change in terms of the typology of Geels and Schot (5). Significant infrastructural innovation in the oil sector supported by new nationally coordinated institutions to implement ambitious wartime production targets, as well as new international institutions and the pivotal role of the US's wartime decisions to gain access to Middle Eastern oil, would provide the infrastructural and institutional foundations for the post-World War II energy regime (19, 24, 38)

Table 3 highlights the broad trends in relation to each mechanism during the shock and the literature relevant to each point.

Table 3: mechanisms of shocks during WWII

Mechanism	Summary
Demand pressures and logistical challenges	Oil supply routes cut off through bombardment; European Allies become dependent on US oil production presenting significant pressure on production and transportation of oil to the battlefield. Vast increase in industrial production for war requires reliable and constant supply of electricity
Directionality	In total war, the energy system was guided by the singleness of purpose of victory in war;
New policy capacities	New national and international institutions (such as the UK's and the Inter Allied Petroleum Committee) in response to crisis.
Shared sacrifice and cooperation	Normal competition suspended between oil firms; energy for citizens rationed to ensure wartime supply;

Overall, diverse literatures highlight significant institutional change, where in a short space of time new institutional arrangements became implemented across the transatlantic zone with new national and international institutions for managing energy supply, trends towards interconnection and centralisation in grids to meet industrial demand, and a refinement in a global oil logistics network and infrastructure pivotal to reduction in costs. Table 4 gives an overview of how these conditions impinged on the dimensions of the sociotechnical system of energy and table 5 summarises how these changes can be considered as a set of amplified rules that were different to prior conditions.

Table 4: Summary of transatlantic energy system dimensions during WWII

Dimensions of energy system	Overview
Science, technology and infrastructures	Increase in oil demand from military and increased oil production; mass production of aircraft; intensified mechanised agriculture further deepening the use of oil in food system. Expansion of refinement capabilities, shipping, logistics, pipelines, and standardisation of fuel types. Further interconnection of electricity grids and in some instances, construction of increasingly large centralised power plant in response to demand challenges. Coal infrastructure damaged in Europe. Unprecedented increase in R&D with implications for energy
Industry strategy and networks,	Consolidation of oil industry and strengthening of industrial networks based around collaboration on key infrastructural projects and innovations such as pipeline development and global oil supply logistics
Policy, politics and governance	Centralised coordination of energy system via war boards and in many cases nationalisation of key industries. New forms of collaboration between government and industry to achieve goals. Efforts made during the war by the US to access Middle Eastern oil and control international oil supply to build the peace. New forms of international policy collaboration around coordination of oil supply amongst allied nations.
Markets and user preferences	Expansion of utilisation of oil into agriculture with mechanisation, pesticides, new fuel types for aviation; energy markets tightly regulated by the state
Cultural perceptions and symbols	Military importance of control of oil; rationing of oil use for citizens accompanied by propaganda for future automobile use associated with freedom. Energy scarcity and blackouts experienced in Europe.

Table 5: rules amplified during WWII

Rule	Trend during the war
Imperative to use oil	marked increase in oil production, refining and infrastructure, and the deepening dependence on oil-based systems of transportation for military use particularly with the growth of standardised aircraft and infrastructure
Imperative of abundance and constant supply	Pressures to overproduce and maintain a consistent delivery of oil and electricity increased markedly. Interruptions in supply could mean defeat in war.
Centralise	Centralisation of management of energy in state institutions; paradigms of centralisation in electricity around grid integration and increasingly large power plant to ensure supply
Internationalise	to meet the challenges of maintaining the delivery of sociotechnical systems for the functions of war, certain countries were brought closer together in order to deal with various logistical challenges, with the Inter-Allied Petroleum Conferences.

4.1.3 Directionality

The exceptional conditions of war fundamentally reshaped the energy system and these changes did not dissipate but constituted a new energy regime. WWII "laid the foundations" of a transatlantic system underpinned by abundant supplies of cheap oil (39). There is widespread agreement in the literature that a new and stable energy system developed in the aftermath of

war across the transatlantic zone with the following trends identified:

- Rapid acceleration in the production and consumption of oil and petroleum. This was particularly rapid in Western Europe with the share of oil in primary energy consumption increasing from 10% after the war to 50% by the late 1960s, and increasing use of oil in variety of sectors including heating, agriculture, transportation, and electrification (32).
- Trends towards centralised and integrated electricity production, based around economies of scale, constant 'baseload' production provided by increasingly large power constituting a stable paradigm of grid design (24, 40) .
- The management of abundance as a new condition for the transatlantic energy system (41–44)
- Stable national institutions and international institutions for the delivery of energy production. (43, 45)

The aftermath of war saw efforts to build the peace with strategic decisions taken including the Marshall plan which saw rapid transitions to oil in Europe (46). However, what is noted in the literature is how these decisions were shaped in a new institutional context that had emerged and was shaped during the war itself (47). Thus the institutions of World War II are referred to as being the 'dress rehearsal' for the systems of the post-war world (48) and a new 'world war II regime' constituting post war systems (49). In MLP terms, we characterise this as a persistence of the rules that had been amplified in the energy system in the post-war period (19). Networks of oil supply had consolidated during the war with the work of inter-allied committees and American plans around Middle Eastern Oil resources. Energy historians note how activities during the war had influenced the acceleration and stability of a paradigm of centralised electricity grids (34). Byrne and Rich (1986) note how institutions associated with energy were inspired by wartime institutions including weapons institutions, and that the new objective of energy policy was to ensure energy abundance with energy efficiency being a secondary concern. Energy relations were defined by interdependence and cooperation across the transatlantic zone between the USA and Europe (51) and the new hegemonic position of the USA that brought stability to the international oil regime, and came about directly as a result of war (52).

We see that there was convergence of rules, stability and persistence of the rules amplified during wartime including an imperative to use oil, maintaining abundance and constant supply, centralisation, and internationalisation. Taken together, these trends are suggestive of a regime shift in the transatlantic energy system, where coal was replaced by oil in a short space of time in many sectors, underpinned by the rules highlighted above imprinting dynamics being an important mechanism of change.

Table 6: Summary of directionality in transatlantic energy system after WWII

Rule	Summary
Imperative to use oil	Manifested in rapid transitions to oil in Europe and specific institutions designed to facilitate oil transitions such as the Marshall plan.
Maintaining abundance and constant supply	Recognised new challenge of 'orderly management of abundance'; transatlantic energy systems geared around rapidly expanding supply, rather than energy efficiency
Centralise	This rule persisted in terms of policy and governance with centralised institutions overseeing energy production as well as technology and infrastructure with centralised grids and increasingly large power plants.
Internationalise	During the war, Europe became a net energy importer predicated on international supply of oil resource under the control of the USA. This trend continued with increased cooperation between Europe and the USA and increased dependence on Middle Eastern Oil Supplies accessed during the conflict.

4.2 The Oil Crisis 1973

4.2.1 Timing

The period of stability discussed above was interrupted when in retaliation at Israeli invasion of the Gollan Heights, nations belonging to the Organisation of the Petroleum Exporting Countries (OPEC) launched an oil embargo against countries supporting Israel including the USA, Netherlands, and Portugal. By 1974 the price of oil had quadrupled. This was a fundamental rupture point in the timeline of the development of a transatlantic energy system that had stabilised after the war (29). The crisis was experienced as a price shock. This exogenous event is more akin to a ***specific shock*** (5) which begins with a specific dimension, however the centrality of energy to economic activity means that there were widespread ramifications across society in general.

With regards to regime and niche there is again broad trends identified in the literature:

- A transatlantic energy regime guided by the rules outlined above was in a stable and mature stage of development (24, 27).
- Niche energy technologies were limited and immature. Some technologies existed in niches associated with the mass mobilisation of science that emerged directly from WWII experience. Nuclear power was central to notions of abundant energy supply (and intimately tied to military imperatives) however contributed less a marginal contribution to the transatlantic energy mix in the early 1970s. Nuclear was the preferred technology for state institutions with R&D budgets for nuclear being substantially larger than for that for renewables of energy efficiency (53).
- In the early 1970s niche technologies such as solar, wind, and energy efficiency, were promoted by civil society groups in new environmental movements that were seeking to replace centralised electricity systems and oil-based energy systems with decentralised renewables and demand reduction (54).

Table 7: Overview of transatlantic energy system before 1973 oil crisis

Focus	Summary
Niche	Despite a long history, niches including wind and solar were not mature; limited investment with R&D for these technologies dwarfed by the R&D for nuclear energy which was the preferred technology for state institutions in many cases tied to military institutions
Regime	Energy system underpinned by internationally sourced cheap oil, centralised electricity grids with increasingly large power plants; some competition in the electricity field between nuclear power and traditional sources such as coal but limited. Institutional stability based around abundant supply; centralisation; internationalisation; no competing rules of energy production other than in emerging civil society groups in the early 1970s but commercial viability.

4.2.2 Oil Crisis 1973: dynamics of shock

The shock period was notably shorter than WWII lasting under one year. However mechanisms similar to those of wartime were present to some extent as politicians emphasised a new war footing in response to the immediate threat of reduced supply in oil. Table 8 summarises patterns of how each mechanism of the shock impacted the energy system.

Rather than stability of institutions emerging from the crisis, there was divergence in national responses in the transatlantic zone and between different actors. Divergent interpretations of the meaning of the crisis and the solutions to it amongst a diversity of actors characterised this period. As Podobnik writes, “for the first time, groups of citizens…became directly engaged in debates over which energy systems should be supported and which should be abandoned” (24, p.120). Contestation centred around environmentalist visions of energy conservation as a means

of departing from energy systems underpinned by oil and centralised electricity generation, and incumbent visions which saw energy conservation as a means of preserving the existing energy regime (54). On the part of these actors, notions of peak oil and the need to substitute oil with new more environmentally friendly technologies were emphasised. Contested visions emerged around the need to diversify energy supply with diversification meaning new sources of hydrocarbon fuels and commitments to nuclear, while alternative visions sought to diversify away from these sources. How energy system dimensions were affected is summarised in table 8, while table 9 summarises the different rules that were amplified by this crisis and how they differed from previous path-dependent trends.

Table 8: mechanisms of shocks during 1973 Oil crisis

Mechanism	Summary
Demand pressures and logistical challenges	The new condition during this time-restricted period was a reduction in oil supply through an embargo and rapid increase in oil price leading to an affective shortage of supply.
Directionality	Immediate factor guiding energy system is how to reduce consumption of oil.
New policy capacities	Rapid measures implemented across the transatlantic zone were enacted by the state to encourage reductions in energy including rationing programmes enacted across the transatlantic as well as efforts to at international response, however in both these cases there was greater diversity of responses and actions.
Shared sacrifice and cooperation	The language of shared sacrifice emerged again during this shock, with discussions of the moral imperative of citizens to reduce energy use for the good of the nation in the USA; however, rather than consensus with regards to this imperative, differences between environmental visions and incumbent visions of the meaning of energy conservation.

Table 9: Summary of change in transatlantic energy system dimensions during 1973 oil crisis

Dimensions of energy system	Overview
Science, technology and infrastructures	R&D expenditures on alternative energy technologies like wind and solar increase in 1973 across transatlantic zone; largest proportion of R&D by far goes to nuclear power and considerable investment made in oil and gas exploration and recovery in new areas such as the North Sea and Alaska
Industry strategy and networks,	Trade flows disrupted; oil companies significantly increase oil prices in response to crisis; transatlantic nations search bilaterally with Middle Eastern countries for new supply routes and agreements between oil majors and producing countries.
Policy, politics and governance	Rationing programmes were brought in to curtail consumption of petrol such as the Emergency Petroleum Allocation Act in the USA including asking gas stations to close on Sundays, imposing new speed limits; implementing daylight saving time, and asking home-owners to refrain from putting up holiday lights. UK, Germany, Switzerland, Norway, and Denmark, placed similar restrictions on driving and flying.
Markets and user preferences	Replacements for oil in particular markets particularly electricity achieved through using coal fired power plants; Energy consumers directly impacted in energy price rises; automobile users impacted with shortages at the pump; and industrial users affected by increased fuel and electricity prices leading to the search for efficiency measures to reduce oil intensity of activities across different sectors.
Cultural perceptions and symbols	Contested visions around the future of the energy regime and what should be continued or abandoned. Different visions of centralised vs local, continuation of oil-based regime vs substitution of oil and centralised generation with new systems based around renewables and energy conservation.

Table 10: Rules amplified during 1973 oil crisis

Rules	Trends during the war
Reduce energy consumption	Immediate imperative to reduce use of oil and electricity; policy interventions guided by this overarching aim
Encourage indigenous supply	Search for solutions to supply shortages through utilising indigenous resources
Diversify energy supply	Find new ways of producing energy as an alternative to oil; coal, nuclear, renewables, natural gas.
Decentralise energy production	More specifically, a new rule that became amplified particularly by certain new R&D institutions and civil society groups was the need for energy to be produced more locally and closer to sites of consumption rather than being reliant on distant energy resources.

4.2.3 Directionality

In the 1970s energy conservation continued to be a priority. Most strikingly perhaps, the Carter administration of the USA committed to the long-term reduction in energy consumption seen as a politically significant departure from the notion of abundance that had dominated post-war energy systems (42). In the 1970s new R&D institutions continued to explore alternative sources of energy (55). However, in the longer term, as Mitchell (56) highlights, ultimately conditions of scarcity and reduced demand rather than threatening oil incumbents, led to regime adaptations and changes in strategy to prospecting for oil in new locations and exploiting natural gas. President Reagan symbolically dismantled solar panels from the White House in 1979 reaffirming commitments to abundant energy supply. Despite a temporary reduction, Energy consumption in Europe continued to grow albeit at a slower rate (32).

Podobnik notes that “by the 1980s most industrial countries had returned to energy consumption patterns that were reminiscent of the early 1970s. Reliance on imported oil and gas resources had again intensified, while few viable alternatives to fossil fuels were under development” (24, P.141). Similarly, Auzanneau (57) points towards incremental innovations in the oil regime that enabled further extraction of oil resources but at a higher price. New oil fields in Alaska and the North Sea became a priority and now economically viable. Another hydro-carbon, natural gas, became increasingly important with production increasing in the UK and the Netherlands in Europe as well as the USA strengthening a hydrocarbon regime (31). During the 1970s nuclear production quadrupled and replaced oil in electricity systems such as in France and the Netherlands however only substituted for 5% of oil consumption mainly in the electricity sector (55). Rather than a shift towards decentralised renewables, diversification in the 1970s and 1980s was mainly driven by new oil reserves, natural gas and nuclear power most notably in France (32). Demand reduction was most forcefully pursued along with wind power in Denmark which can be considered a niche in the transatlantic zone. However, it was not until the 1990s that solar and wind energy began to grow their share in electricity production at an initially slow rate.

Oil persisted as the main technology in the primary energy mix in the transatlantic zone for decades remaining so to the present day rather than new forms of energy production replacing oil as a result of the crisis. Indeed, Smil (55) points out how predictions of the 1973 oil crisis being a terminal moment for oil and a rapid decline ensuing had not come to fruition the transatlantic energy system remains stubbornly underpinned by oil and centralised electricity supply (55). It was not until the 1990s, that changes towards more decentralised options were pursued in policy,

suggestive that the enhanced policy support for these niches was not driven by the imprints of the shock itself.

Overall then, this shock was more narrow in its scope; less intense in terms of the dimensions implicated; and occurred at a time when niches were underdeveloped. What did occur, was divergence both between different groups in countries and countries. The general trends see regime reconfiguration and the adoption of innovations to ensure overall continuity of an energy system geared around hydrocarbons and centralised electricity generation, however opportunities were taken by civil society groups and activists to influence the support of niches such as wind, solar and a paradigm of energy sufficiency as opposed to abundance (41).

Table 11: Summary of directionality in transatlantic energy system after WWII

Rules	Trends during the war
Reduce energy consumption	While reducing energy consumption remained significant in the 1970s this rule became less of a priority in many place in the transatlantic through the 1980s, with a renewed focus on maintaining energy abundance and constant supply in countries like the USA and UK, facilitated by the exploitation of new oil reserves.
Encourage indigenous supply	The transatlantic zone continued to be largely dependent on international oil regime including oil sourced from OPEC countries.
Diversify energy supply	Minimal diversification of supply took place; diversification mainly oriented around gas and nuclear and confined to a select few countries. Renewables remained marginal and lacking firm policy support until the 1990s.
Decentralise energy production	Electricity systems remained centralised. In certain niches, most notably Denmark, decentralising through the implementation of district heat took place. However, decentralised renewables were not vigorously supported in policy until the 1990s and later in the case of many transatlantic countries.

5. Discussion

We set out to compare two archetypal shocks and their effects on the transatlantic energy system from an MLP perspective through combining attention to timing, dynamics of the shock period, and the subsequent directionality following the shock in the longer term. We conducted a narrative analysis based on a sociotechnical analysis of typologies of transition pathways, and attention to two approaches to understanding the role of shocks: the dominant windows of opportunity approach, and notions of imprinting. These approaches contrast in the sense that windows of opportunity approaches focus more on the decision point in terms of policy makers ability to influence trajectories in sociotechnical systems (58), whereas imprinting is more focussed on the conditions of an exogenous shock and how these particular conditions impinge on sociotechnical systems. Rather than distinct, based on our analysis, we argue that exogenous shocks should be considered in terms of the degree to which the conditions of the shock continue to influence directionality, or the extent to which a particular shock leads to a window of opportunity where different directions for policy become possible. In relation to the comparisons identified in table 12 below, we make the following propositions: shocks with greater intensity affecting several dimensions of a sociotechnical system occurring at a time when niches are mature are likely to lead to significant imprinting. Shocks that affect fewer dimensions and occur at a time when niches are not developed are more likely to present a window of opportunity.

Table 12: Overview of salient differences between shocks

	World War II	Oil Crisis 1973
Timing	Occurred at a stage of competition and instability in the transatlantic regime when niches were mature and well developed	Occurred at a time of stability in the regime when niches were many niches were not mature
Shock dynamics	Avalanche change; Intense effects of mechanisms on sociotechnical system affecting all dimensions; notable infrastructural changes; strong consensus and collaboration across society, industry and government	Specific shock of availability and cost of oil; more limited number of dimensions affected, for example, no significant infrastructural change or change in energy market rules
Rules	Rules amplified with significant effects on system including: imperative to use oil; abundance and constancy of supply; centralise; and internationalise	Rules including imperative to reduce demand; encourage indigenous supply; diversify supply and decentralise energy supply become amplified with different material manifestations of these rules
Directionality	Convergence towards institutionally stable regime across the transatlantic zone	Divergence of competing visions of transatlantic energy regime; reconfiguration and continuation of regime rather than significant meso-level change
Window of Opportunity/ imprinting	The persistence and stability of the rules amplified in wartime, the convergence across the transatlantic zone, is suggestive of significant imprinting dynamics.	Rules amplified during the shock did not persist for long; divergence amongst countries and actors was evident; suggestive of a window of opportunity and limited imprinting

Based on this analysis and in the context of prospective sustainability transitions and current and future shocks some recommendations follow:

- The ***Dynamics of shocks*** should be examined further in sustainability science. Rather than external shocks being presented in similar terms regardless of the type of shock, different exogenous shocks entail differing dynamics which can affect sustainability transitions. Different shocks have different mobilising forces that deserve more attention.
- It is important to identify the ***Constraining*** as well as enabling conditions of shocks. While there is an implicit portrayal of shocks leading to an opportunity (5), World War II is suggestive that the shock was constitutive of the nature of subsequent sociotechnical developments and institutional stability constraining opportunities for divergence.
- It is important to take into consideration how a shock affects different ***dimensions*** system. For example, WWII is particularly significant in terms of how infrastructures were radically altered during the shock phase that became reconverted into civil life. Similarly, energy markets were radically altered. The effects of shocks depends on how different dimensions are affected.
- There is a tendency to view the effects of shocks in technological priorities made in policy decisions following the shock event. However, it is important to focus on ***rules*** or institutions and the extent to which these change or not. For example, following the 1973 crisis, while it seems that significant change occurred with the noted encouragement of renewables and efficiency, a longer-term perspective shows a limited change in the rules directing the energy system in most transatlantic countries. In terms of more radical meso level change, changing the deeper rules that influence unsustainable systems is a priority.

While these are historical case studies, as we alluded to at the front, researching the different effects of landscape shocks has never been more of a priority with transatlantic energy systems facing a threat not seen since 1973 in terms of the war in Ukraine and gas crisis. Despite the maturity of renewables it is recognised that in many instances more rapid diffusion is not taking place and we are in a 'stagnating acceleration phase' (59). Such an event as the current war in Ukraine and its ramifications can also fundamentally change the rules and institutional responses occurring, the geopolitical patterns of production and trade, the relationship between military systems and energy, that could imprint on subsequent developments for decades to come. Attention to both imprinting dynamics and windows of opportunity can assist in more comprehensive understandings of where constraints and opportunities for change are present following exogenous shocks.

History shows us that rather than external disrupters of the directionality of our energy system, shocks are a constitutive part of the nature in which the energy system develops. In this age of perpetual crisis, it is time that the dynamics of shocks and their consequences was put centre stage in sustainability transitions analysis.

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