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How will renewables expansion and hydrocarbon decline impact security? Analysis from a socio-technical transitions perspective

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ABSTRACT

Security implications of zero-carbon energy transitions have only recently received more focus. Overarching analyses in transition studies are lacking. Therefore, we combine concepts of positive and negative security with transitions research to analyse the security issues associated with the unfolding transition. We create a framework that explores security via two dimensions: renewables expansion and hydrocarbon decline, suggesting three elements for 'decline': disruption to and repurposing skills/assets, unlearning and deep learning, and deinstitutionalisation and shifting pressures. Six security themes were identified from 60 expert interviews in four countries: energy security, defence, electricity system operability, cyber security, geopolitics, and internal stability. Expectations regarding security are polarised around more or less secure future systems. Positive security is dependent on how regime decline is managed. Learning and unlearning, new social network building, and deinstitutionalisation can create complementary processes. Transitions may stall, with negative security implications, if skills/assets are not reconfigured to new system contexts.

1. Introduction

The social implications of sustainable energy transitions are increasingly recognised. Yet, the sustainability transitions literature has devoted only limited attention to how transitions affect security – which has become a key concern following the 'landscape shock' of Russia's attack on Ukraine in 2022. Contrarily, the literature on the geopolitics of renewables has for some time recognised that the energy transition will have a range of effects on geopolitical security via shifts in the resources required, security of supply, and states' power relations (Goldthau and Westphal, 2019; Scholten, 2018; Wilson, 2018). Also, energy security, i.e., low vulnerability of vital energy systems (Cherp and Jewell, 2014), gets new meanings via the zero-carbon energy transition. These include, for instance, the availability and supply of critical materials and technological components for renewable energy production (Lee et al., 2020; Øverland, 2019). While the concept of energy security has over time expanded with multiple new categories proposed (Azzuni and Breyer, 2018; Sovacool and Mukherjee, 2011), it has simultaneously become more difficult to understand, essentially becoming polysemic (Chester, 2010). There are also other links to security via the effects of renewable energy on peace and conflict (Goldthau and Westphal, 2019) and right-wing populism (Żuk and Szulecki, 2020). Hence, the security implications of energy transitions are quite complex and can be narrowly or more broadly defined. Our approach here aims to provide a broad perspective on the topic.

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Research on the geopolitics of energy transformation has noted that a whole systems approach, covering both renewable energy expansion and hydrocarbon decline, is needed (Blondeel et al., 2021), and that systematic empirical data is scarce (Vakulchuk et al., 2020). Further, the literature on energy security and geopolitics typically lacks a socio-technical perspective. Therefore, in this article, we study expectations on how energy transitions influence positive and negative security from a transitions research perspective. We do so by connecting the concepts of positive and negative security to two sides of the energy transition: niche development/expansion and socio-technical regime decline; and by examining expert perceptions in four European countries: Estonia, Finland, Norway, and Scotland/UK. The countries are interconnected by cross-national electricity transmission networks but differ in their energy and security policy approaches. Estonia, Finland, and Norway were selected as they are all small states with less than 6 million population and share a border with Russia; small countries have attracted little attention in the literature on energy geopolitics and security. We also chose Scotland as a small country with independence pursuits from the UK and with large fossil and renewable energy resources, the latter emphasised in Scottish energy pursuits. We aim for an overarching view and explore a variety of security implications of the unfolding transition, going beyond how energy security is typically conceptualised.

Security as a concept is broad with multiple dimensions and interpretations. Its meaning has over time extended from the traditional 'realist' interpretation of national security as a protection against military threats (Buzan et al., 1998) to covering, for instance, human and environmental security (Peoples and Vaughan-Williams, 2015). A low probability of potential harm, or the preservation of acquired values (e.g., territorial integrity, human survival, sustainability) is one definition of security (Baldwin, 1997). This kind of definition emphasises threats of 'negative security'. In addition, 'positive security' has been defined as the presence of conditions that further human well-being (Gjørv, 2012), emancipation, peaceful relations, and freedom from insecurity (Booth, 2007). Leaving the understanding of security broad and open, we address the following research questions: What kind of security issues are associated with the unfolding zero-carbon energy transition? How do these security issues play out in the context of niche development/expansion and regime decline processes? Our analysis is empirical and based on thematic and deductive analyses of 60 interviews with energy and security experts in late 2020 and early 2021 in the four countries.

The paper is organised as follows: Section 2 briefly introduces the literature on the geopolitics of renewables. Section 3 draws from transitions research to outline a conceptual-analytical framework for the analysis. Section 4 describes the research approach and methods. Section 5 presents the findings, and Section 6 discusses. Section 7 concludes.

2. Literature on the geopolitics of renewables

Observations about security are linked to geopolitics which means broadly "the interaction between geographical factors, politics and international relations" (Högselius 2019, 7). The geopolitics literature has two main strands: (1) the classical realist geopolitics, examining the influence of geographical factors between states (Blondeel et al., 2021) and the states' needs to secure territorial access and resources (Dodds, 2014), and (2) critical geopolitics addressing how geographical assumptions are utilised in global politics (Kuus, 2010), questioning dominant power and knowledge structures (Högselius 2019; Tuathail, 1999).

The geopolitics of renewable energy literature has rapidly expanded, and a new research agenda has emerged (Blondeel et al., 2021; Vakulchuk et al., 2020). Its key arguments are that geographic and technical characteristics of renewable energy systems differ essentially from those of hydrocarbons and that the effects on interstate relations will be significant (Scholten et al., 2020). Some recurrent themes include, also, renewable energy's peace and conflict potential, and likely winner and loser countries (Vakulchuk et al., 2020).

Much of this literature deliberates that the transition reduces geopolitical risks around energy. Blondeel et al. (2021) state that, via the transition, the use of energy in a coercive way in international relations is reduced. Scholten et al. (2020) identify clusters of geopolitical implications from renewables, such as shifting to less oligopolistic global markets and prosumer countries, reduced volume of energy trade, and electrification and regionalisation of energy relations. Øverland (2019) sees fewer risks due to more even geographical distribution of resources. Vakulchuk et al. (2020) argue that renewables may cause small conflicts but reduce large ones, as they are less affected by resource scarcity, location, security of supply or international competition. They also note a difference between the transitional phase and the new system, where the former is likely to have a destabilising effect on global security, resulting from possible reactions from hydrocarbon exporters, new kinds of interdependence between states, and armed threats from non-state actors.

Research on the strategies of hydrocarbon-exporting nations show diversity in responses to the net-zero transition. While some examples of temporary moratoria on coal-mining leases exist (e.g., US, China) (Blondeel and Van de Graaf, 2018), many countries also pursue ways that enable the continuation of fossil fuel production. Some use new conceptualisations such as the 'blue economy' to legitimise the development of hydrocarbons (e.g., Canada) (Fusco et al., 2022). Others aim to increase fossil fuel production by dissonance, i.e., emphasising climate efforts and climate diplomacy simultaneously (e.g., Norway) (Boasson and Lahn, 2016). In addition, the hype about hydrogen has been argued to provide a new opportunity for natural gas producing countries (Blondeel et al., 2021).

Criekemans (2018) takes a rarer technological perspective in examining the geopolitics of renewable energy. He explains how the energy technology revolution will shape geopolitics, not only by changing the power relations between states but also by diffusing power from states to individuals. Many scholars have focused on geopolitical competition over critical materials but these risks "may not materialize because materials can be recycled, alternative materials and technologies might be developed, materials need to be imported only once to build installations, [and] new deposits may be discovered…" (Scholten et al., 2020: p.2). Following electrification, the emergence of regional grid communities where countries mutually depend on each other for electricity transmission, is regarded geopolitically significant (Blondeel et al., 2021; Scholten et al., 2020). Vakulchuk et al. (2020) notes several research gaps, such as lack of distinction between different types of renewable energy and of methods-based and empirical research. We address the latter here.

The connections between energy security and transitions are significant because the rapid electrification of societies creates new insecurities (Szulecki and Kusznir, 2018). Yet, literature on the transitions' energy security impacts is limited. Jewell et al. (2014) argued that decarbonisation brings substantial energy security benefits, enhancing the connection between climate change mitigation and global energy security. Also new security concerns may arise with the transition, such as competition for land (Johansson, 2013; Jonsson et al., 2015) and critical materials (Hache, 2018; Lee et al., 2020), and increased surface areas for cyber-attacks (Cornell, 2019). Mata Perez et al. (2019) examined the opportunities and challenges of the energy transition to European energy security, noting divergent national interests and energy foreign policy strategies. They argued that some regard transition as an industrial opportunity that reduces import dependence, while others prioritise reliable supplies and consider renewables as too volatile; contrary perceptions of energy security have led to a different speed of energy transitions in different countries. A similar argument was made by Szulecki and Kusznir (2018), the transition being both an aid and a threat. While, in Germany and Poland, renewables were seen as an opportunity for energy security, the possible threats outweighed the benefits in terms of reliability of the transmission grid and energy independence (Szulecki and Kusznir, 2018).

Security either as a force shaping transitions or something that is shaped by the unfolding transitions has not received much interest in socio-technical transition studies until relatively recently. Johnstone and Newell (2018) argued, from the perspective of 'hard security', that the military establishment has not been included in the theorisation of transitions. They described militaries as the means by which states can implement their energy-focused foreign policies. In another article, Johnstone et al. talked about a 'military-industrial complex' and a 'national security state' as incumbent actors who have vested interests in the existing socio-technical regime, and who may try to hinder the expansion of niche innovations (Johnstone et al., 2017). Similarly, Geels (2014) has acknowledged the military as part of fossil fuel alliances. Verbong and Geels (2010) have in passing referred to geopolitical security and energy security as major landscape threats in transitions. More recently, Johnstone and McLeish (2022, 2020) utilised a deep transitions framework to examine the role of oil in the Second World War, influencing the subsequent oil-based energy transition. Kivimaa and Sivonen (2021) analysed the connections between low-carbon energy policies and national security policies from the perspective of transitions, and Kivimaa et al. (2022) utilised a socio-technical lens to assess the security implications of transitions.

3. Socio-technical transitions research

Sustainability transitions concepts are well known to the audience of this journal, so we only briefly review the key concepts: socio-technical regimes and niches. Regimes are the deep, established structure of socio-technical systems (Geels, 2004) comprising multiple dimensions: science and technology, market structure and user preferences, industry structure, policy and politics, and cultural meanings. These dimensions imply that transitions are about transforming not just technical systems but the underlying rules that different actors use to construct, optimise, and manage the socio-technical system (Ghosh et al., 2021). Regimes can be destabilised and de-aligned via contextual landscape influences, creating windows of opportunity for niches to expand (Geels, 2020), while such processes are not easy due to the path-dependent nature of regimes.

Niches are protected spaces (e.g., specific markets or geographical areas), where niche innovations with potential to disrupt the dominant regime grow and mature (Kemp et al., 1998; Smith and Raven, 2012). Niche development has frequently been described via three processes: articulation and navigation of expectations, building of social networks, and learning (Table 1). We will use these processes to depict renewable energy expansion in our analytical framework as they have had seminal influence and are empirically well-proven in multiple studies. While other processes, such as institutionalisation and replication, have been described for niche expansion by Naber et al. (2017) and Ghosh et al. (2021), these processes are less suited for the examination of security impacts, because they all address in essence the upscaling of new technologies and provide little nuance to analyse the unfolding of security impacts.

Table 1
Processes of navigating expectations, social network building and learning in niche development.

Niche development process	Grounding in literature
Navigating expectations	Diverse actors participate in niche building processes and individual expectations shape into niche actors' collective expectations about future movements and shocks at the landscape level, how regimes will respond to these, and which potential niches offer. These expectations can be volatile. Expectations direct learning processes and attract attention from more actors and resources. This process is fruitful if actors start having same expectations, and expectations become more precise (van der Laak et al., 2007; Schot and Geels, 2008; Ghosh et al., 2021).
Social network building	In the early stages of niche development, social networks are weak, while transitions depend on the interaction of multiple actors. Networks are created to build a community behind the niche by enabling exchanges and allocating resources. Over time the networks may become also attractive to actors engaged in established regimes. The process is successful if networks are broad, oriented towards deep learning and regular interaction is supported (van der Laak et al., 2007; Schot and Geels, 2008; Ghosh et al., 2021).
Learning	Niche development occurs via diverse forms of learning, e.g., technical, market, cultural and policy learning supported via multiple experiments. Learning can be described as a perceptive process of knowing, understanding, and reflecting. Deeper learning that moves from assembly of data to altering cognitive frames and assumptions is important. The process is successful if it combines technological change with societal embedding in local contexts, addressing multiple dimensions (van der Laak et al., 2007; Schot and Geels, 2008; Ghosh et al., 2021).

The decline of established socio-technical regimes was initially little addressed in transitions research but, over time, it has received increasing attention. The transitions literature has been argued to have an 'innovation bias' by overemphasising novelty and under-theorising the deconstruction of existing configurations (Feola et al., 2021). Feola et al. (2021) posit that the creation of new spaces involves the disruptive side, i.e., construction is coupled with destruction, experimentation with resistance, and propositions with refusal. Therefore, they see '[p] processes of deconstruction, rupture and disarticulation as *conditions for* rather than *consequences of*' transitions (Feola et al., 2021).

Much of the discussion thus far has focused on conceptualisations of and empirical studies on regime destabilisation (e.g. Kungl and Geels, 2018; Normann, 2019; Roberts, 2017) and phase-out (e.g. Andersen and Gulbrandsen, 2020; Isoaho and Markard, 2020; Rogge and Johnstone, 2017). Van Oers et al. (2021) notes that destabilisation has become a focal object of study, while it was earlier regarded as a background process of innovation, having two distinct lines of research: a flip-side of innovation process and an object of governance. Whereas the destabilisation literature takes a more holistic system-level perspective, literature on phase-out has tended to focus on technological decline (Andersen and Gulbrandsen, 2020; Koretsky and van Lente, 2020) and discourses (Rosenbloom, 2018; Trencher et al., 2019). The decline of regimes relates to the notion of incumbency that has typically been tied to the idea of path dependence and opposition to transitions. Yet, there is increasing nuance in how incumbency is structured and involved in the transition processes (Stirling, 2019).

Here we draw from these and connected literatures to propose selected analytical categories for regime decline which we consider useful for the analysis of transitions' security implications. Table 2 outlines our proposed categories and their grounding in literature: disruption to and repurposing skills and assets, unlearning and deep learning, and deinstitutionalisation and shifting pressures. We do not claim these are the only relevant processes, but these can be derived from the nascent literature on regime decline for our analytical purposes, to uncover the security implications of declining hydrocarbon regimes. Additional or alternative categories may be helpful for the analysis of decline from different perspectives than the one taken in this article. Further, it is important to note that any decline process may not unfold in full, but some parts or remnants of the declining regime can persist. The transitions literature has, for instance, paid attention to a process of reconfiguration where the regime experiences a substantial shift while maintaining some of the actors, skills and other components (Laakso et al., 2020). Furthermore, the literature on deinstitutionalisation has shown that institutionalised elements do not fully disappear in the process (Novalia et al., 2022).

The processes pertaining to niche development and regime decline happen in dynamic influence with each other. It is also important to understand that they are socially constructed processes that in the real world are much more fluid and overlapping (Stirling, 2019). We are using them here in an atypical context for transition studies, to explore expectations of the security implications of transitions. The security dynamics relate to transitions: as potential positive security expectations (e.g., via reducing dependencies and enabling communities in transitions) and negative security expectations (e.g., creating new types of existential threats, dependencies, or tensions in societies and between states). Fig. 1 illustrates our analytical framework composed of the two main transition processes (niche development/expansion and regime decline) and their sub-processes used in this study.

Table 2
Processes of disruption to and repurposing skills and assets, unlearning and deep learning, and deinstitutionalisation and shifting pressures in regime decline.

Regime decline process	Grounding in literature
Disruption to and repurposing skills and assets	Disruptive innovation and resulting regime destabilisation processes create changes, whereby existing skills, competences, knowledge, and resources may become reduced in value, and in extreme cases obsolete (Abernathy and Clark, 1985; Kivimaa and Kern, 2016). In an industrial context, this means that the value of incumbents' expertise and other factors of production reduce significantly (Abernathy and Clark, 1985). Destabilisation is argued to weaken the flow of resources into the reproduction of regime elements such as core technologies (Turnheim and Geels, 2013) and financial resources (Rosenbloom and Rinscheid, 2020). However, recent research also shows, e.g., in the Covid-19 pandemic context, that actors can quite rapidly repurpose their skills to new types of commercial operations (Nemes et al., 2021). For instance, Norwegian oil and gas industry companies have sought new corporate ventures in offshore wind mainly because they were able to repurpose their existing resources (e.g., technological and market expertise) (Mäkitie, 2020).
Unlearning and deep learning	Unlearning and deep learning are connected to processes that destabilise existing socio-technical regimes. Unlearning is a process that results in discarding old obsolete practices and ineffective habits (van Mierlo and Beers, 2020), establised routines and mental models (van Oers et al., 2023) via consciously not thinking or acting in old ways (Stenvall et al., 2018). It has been described as a continual and reflexive process of identifying how our conceptualisations of the world are unselfconsciously bounded (Lawhon et al., 2016). It is about rejecting and questioning taken-for-granted values, norms and beliefs (Feola et al., 2021) that are often associated with incumbency and the structuring of power (Stirling, 2019). Unlearning means accepting a certain risk and uncertainty about the future regime and, hence, connects to deep learning, i.e., 'experiential social learning' about challenges facing the extant regime and constructing new in-depth knowledge about the changing system dynamics (Ghosh et al., 2021).
Deinstitutionalisation and shifting pressures	Deinstitutionalisation is a process, where legitimacy is eroded in the context of shifting social, political and functional pressures; implying changes in underlying interests and power relations, structures of leadership and authority, and reducing cultural consensus (Novalia et al., 2022). Key actors in (de)institutionalised structures may be replaced (Kivimaa and Kern, 2016; Turnheim and Geels, 2012) organically or in response to deliberate attempts. Dominant actors may lose influence and legitimacy when markets decline, value chains and networks break up with weakening expectations connected to changing landscape pressures (Markard et al., 2020), while they also resist this process by seeking renewed roles in the new system (Mäkitie, 2020) that re-legitimise their position.

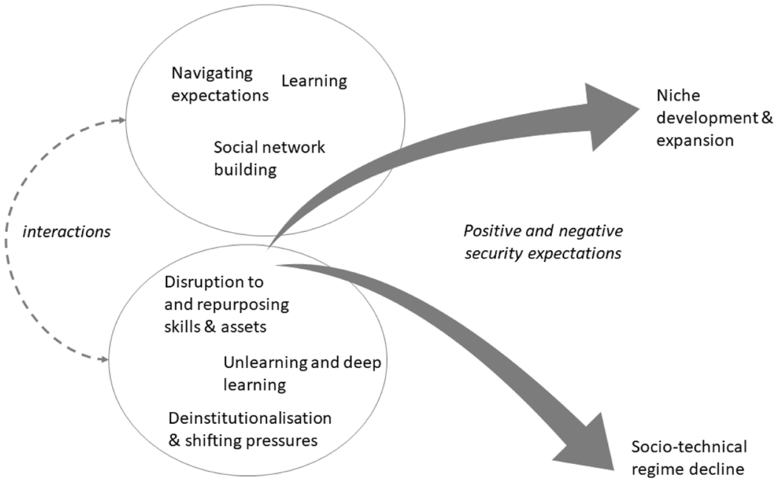

Fig. 1. Analytical framework.

4. Research approach and methods

The principal research method is semi-structured in-depth interviews. We studied the perceptions of expert actors on the security implications of the energy transition before the 2022 energy crisis occurred in Europe, and identified experts in four countries (Estonia, Finland, Norway, and Scotland/UK) based on our previous knowledge, organisational websites, and recommendations from those interviewed. The interviews covered most people with expertise in the energy-security nexus in each country, as this was a topic not well known to many people prior to 2022. Despite the changed circumstances, many of the security perceptions from the time of the interviews appear still valid now, if not more so. We will reflect on this in the discussion section.

The questions focused on key interactions between energy and national security policy, synergies and conflicts between the energy transition and national security, and the security implications of the decarbonising and electrifying energy system. We conducted in total 60 interviews with 64 experts in the fields of energy, national security, defence, international affairs, and cyber security. In the UK, we focused on Scotland in our interviewee selection due to its extensive renewable energy and oil resources. The interviewees included people from the public administration, the energy industry, academic research, and party politics (Table 3).

We conducted a thematic analysis of the transcribed interviews in NVivo, where the first author coded 53 and the second author 12 interviews. To improve intercoder reliability 5 interviews were jointly coded. The coding resulted in 11 themes referred to in more than 10 interviews (indicated by top codes), which were further refined for our analysis by reading through the materials. This was reduced to a list of 6 themes addressed in the findings. Similarly to Johnstone et al. (2021), we took the more frequent occurrence of similar perceptions between interviewees to provide evidence of a stronger finding. As a second step, we cross-coded the thematic issues with the six elements in our analytical framework. The results provide a status of expectations in these countries prior to 2022, explaining the context of expectations in which the current energy crisis occurred.

Fig. 2 shows the energy mix in 2019–2020 of the countries where the experts were based at. Norway was much more electrified than the UK, followed by Finland and Estonia. In turn, Finland had the largest share of renewables and biofuels (not counting electricity production) and the UK led with the share of gas and other fossil fuels.

5. Results

This section first examines the expansion of the renewable energy and electrification -based niche from the perspective of three processes: expectations, learning and networking. It then inspects the decline of the hydrocarbon-based regime via decline processes: disruption to and repurposing skills and assets, unlearning and deep learning, and deinstitutionalisation and shifting pressures. The security themes are presented in the order of frequency mentioned by all interviewees. Divergences between countries and different actor categories are also briefly compared.

5.1. Expansion of the renewable energy and electrification -based regime

5.1.1. Energy security

Energy security, discussed in 42 interviews, covers many dimensions. The ***expectation*** dynamics for the expansion of renewable energy (and longer in the future perhaps green hydrogen) included enabling positive security via improved security of supply, as well as threats, i.e., negative security, as risks related to the supply and availability of critical materials and renewable energy technologies. A very common expectation in Estonia (ES), Finland (FI) and the United Kingdom (UK), and among all actor categories, was that renewable energy increases countries' self-sufficiency in energy supply and reduces insecurity around fuel trade. This means, for

Table 3
Categorisation of interviewee profiles.

	Public administration	Industry/business	Research	Politics
Estonia ($n = 15$)	6	2	6	1
Finland ($n = 15$)	5	3	4	3
Norway ($n = 15$)	5	3	5	2
UK/Scotland ($n = 15$)	5	1	6	3
Total	**21**	**9**	**21**	**9**

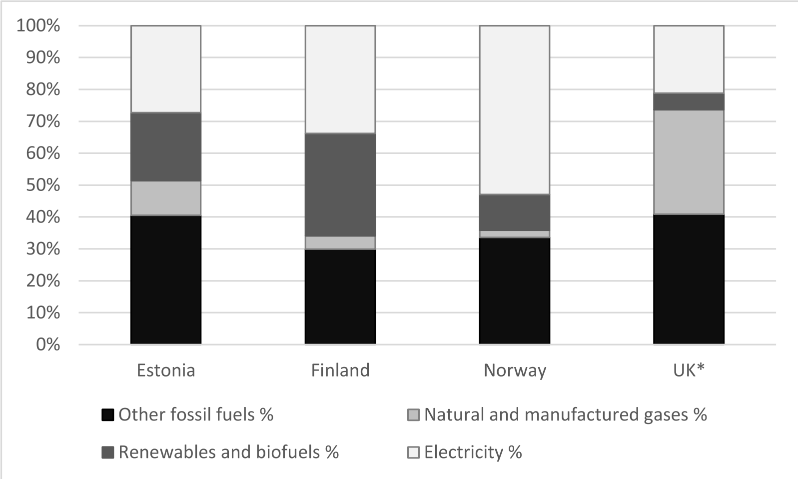

Fig. 2. Final energy consumption by product and by country in 2020. UK* data from 2019 due to data accessibility. Source of data: Eurostat, 2023.

instance, less vulnerability to supply crises and price spikes (landscape shocks) via diversified and distributed supply of renewable energy. Only a few interviewees (ES, FI) mentioned microgrid-related expectations to improve local security of supply and create distributed resilience less influenced by external shocks. There were singular concerns (ES, FI) about the reliability of the new energy system based on renewable energy, especially in crisis situations. Selected people (UK) expected energy storage, still a niche technology, to improve reliability also in crisis situations. Green hydrogen was seen as one future option alongside electrification to decrease the vulnerability of the energy system and reduce hydrocarbon dependence of transport and industry (ES, FI).

An expectation around negative security in Finland, Norway (NO) and the UK, and especially among politicians and public administration actors, related to the availability and price of renewable energy technologies and critical minerals and metals, especially rare earths, needed in their production and in smart grids; largely imported to Europe. For example, semiconductors are important for the digitalisation of the grid. The technologies and components are manufactured in concentrated locations, influencing the initial purchase and fixing installations. Much is concentrated in Chinese ownership.

The ways in which these security expectations will realise, depends on ***learning***. Renewable energy, once installed, is a universal source of energy but dependent on technologies to capture, transmit and store energy; hence, technology requirements become the focus of new energy security. The development and scaling of energy storage and new grid structures, such as localised smart grids, demand side response and digital platforms are needed for the new system to be secure. Smart energy solutions bring also new vulnerabilities (FI, NO, UK) via electrification of transport and broader network complexity that require learning efforts. Another element is a dependence on large universities and global companies that have the knowledge and skills to research complex niche energy technologies, such as batteries (FI). Some talk about the idea of 'a clean-tech cold war' or 'green arms race' (UK), where the emphasis on controlling materials, technologies and supply chains will be critical for the future of the energy regime. Yet, others see less supply risks than in hydrocarbons because some supply concerns may be managed by minimising the use of critical input materials via learning and innovation (NO, UK). Green hydrogen was seen to be quite far in the future, with much learning and international partnerships required where and how hydrogen could be an option for hard-to-decarbonise sectors (ES, FI, UK).

Energy security of new regimes will also depend on ***social network*** dynamics, the evolution of interactions between global actors (states and global companies) and the emergence of new grid communities. Integrated electricity networks create interdependencies with neighbouring countries (NO) and extend the idea of security of supply from within individual countries to regional grid communities, which can contribute to social network building resulting in positive security. The availability of renewable energy technologies and critical materials, in turn, depends on how state and other actors' relations develop. Low-cost technologies have already driven down domestic supply chains in Europe. China has developed into a major player in critical materials, by strategic action to have a concentrated ownership of materials, such as lithium and cobalt, buying up mines in different parts of the world and reducing its technology dependence on Western countries. It has specifically increased its control of mineral developments in Sub-Saharan Africa.

Many interviewees highlighted uncertainty around how this critical materials question will develop.

5.1.2. Defence

Thirty-two interviewees mentioned connections between energy transition and defence, mainly regarding the interference of wind power in the operation of defence radars. The broader ***expectations*** were that decarbonisation, renewable energy, and smart-grid technology, first, reduce climate security concerns via reducing emissions, and second, offer opportunities for the military sector (ES, FI, UK). Micro-grids are expected to improve the supply security of military areas, and reduce the vulnerability caused by risk of attacks to oil or gas tankers (ES). While increase in wind power is expected to be beneficial for security by increasing energy independence, in Estonia and Finland, the expansion of wind parks and the increased height of wind turbines, i.e., upscaling of the niche, have caused some tensions between the defence and energy administrations. This relates to the operation of air surveillance radars and signal intelligence in important areas close to the Russian border. Solving this issue depends on learning and networking.

Learning here pertains to military R&D and resolving conflicts between defence air surveillance and wind power by new technical and governance solutions. In the latter context, learning is integrally intertwined with ***networking*** between the defence and energy administrations. In Finland, this issue is mostly described as a small disagreement which has been generally resolved via networking between the national grid operator, the defence forces, and different ministries (also illustrating the need for incumbent actors to be part of the networks when niches expand). The defence forces' good societal networks have enabled reaching a shared understanding, linking to deeper learning. The technical challenge of radar and radio signals being interfered by wind turbines has been addressed by learning about alternative solutions and understanding the necessities of defence. New radar equipment has been purchased, while the high cost is still an issue.

In Estonia, this issue led to a court case pursued by companies that wanted to build wind parks. It has been partially solved by learning and networking between the actors involved. While initially criticised as strict and short of discussion, later the Ministry of Defence opened to discussion and learning, finding solutions to fund new radars, and understood how wind power can also work towards national security by diversifying the energy system. A government decision to invest in radars that allow the building of wind parks was made with novelty in how radars are funded.

In Norway, some interviewees mentioned wind power influencing radars near military bases, but this was not regarded as significant. The same was mentioned in the UK but has been resolved with new technology.

5.1.3. Electricity system operability

Issues regarding electricity system operability when renewable energy and electrification increase were identified in 31 interviews. ***Expectations*** differed from seeing these changes as a more negative risky development, to a technical, solvable issue. Most interviewees saw it as future development where both risks (negative security) and opportunities (positive security) for system operability exist. The expectations around negative security pertained to decreases in energy system reliability via intermittency and increased risk of system disturbance (ES, UK). Many noted that new electricity systems require more balancing capacity[1] (ES, FI, UK). Different solutions creating positive security were mentioned, such as improved storage (ES, FI, UK), interconnected electricity networks (FI, NO, UK), demand response (ES, FI), and bioenergy or synthetic fuels (ES). An expectation was also presented whereby the transition leads to a model, where demand response, storage and consumption guidance combined with smart meters, services and digitalisation remove the balancing requirement (FI).

The transition is expected to require improved electricity grids and new transmission capacity. Many expect the new energy regime to improve system security via decentralisation, meaning a smaller influence of any disruption than in large, centralised regimes. One interviewee stated that individual 'cells' of the system can be disturbed but the whole system does not fall. This was often described in the context of improved system resilience. An interviewee remarked that power systems have already proven to be incredibly resilient with expanding shares of renewable energy. Electrification was also noted in the context of interconnected regimes, with disturbances having larger effects on the rest of society such as communication system or electrified transport (FI, NO, UK).

These responses emphasise not only technology but ***learning*** in enabling transitions. Especially public administration actors and politicians described a more complicated future system via renewable energy, back-up and needs for data management. One interviewee described this as a significant engineering challenge, bigger than any engineering change in the electricity sector for more than a century (UK). Also, decisionmakers need to learn about the resilience effects of new technologies.

Social networks will change as electrification creates new kinds of needs. A potential security link connects to geopolitics and state actors (see also Section 4.1.5). As the transition requires increasingly interconnected electricity networks, there is cross-border reliance on neighbouring countries (FI, NO, UK), with at least a theoretical risk of being cut off following technical problems or political friction – effectively, an old problem of dependencies between countries. European and Nordic transmission connections and networks are seen as strong, well-functioning and stably governed. Yet, there is a need for new regime rules, such as a degree of harmonising regulation or a regional forum to coordinate energy security and crisis management. Also, decentralised, prosumer-based models were argued to need an actor that is responsible for security of the system against disturbances and external attacks, because small actors do not have these resources.

[1] Balancing capacity is the volume of reserve capacity in the electricity system.

5.1.4. Cyber security

Cyber security was mentioned in 27 interviews. As above, some expected a higher level of cyber risks due to a more complex renewables-based energy regime (FI, NO, ES, UK), while others expected decentralised renewables to reduce vulnerability to cyber threats as the nodes of electricity production are small and more diffused (UK). Cyber risks were frequently connected to an increasingly electrifying energy system with digitalised grids that create major vulnerability problems (FI, NO, ES, UK) due to dependence on telecommunications and data management systems. The ***expectations*** of increasing cyber security risks were connected more broadly to modern digitalised knowledge-based systems. Energy infrastructure is a key area of cyber security with contemporary examples of hydropower plant shutdowns.

The largest risk mentioned was an attack harming the real-time balance of demand and supply that would paralyse the whole society for a few days, with implications on water supply, transport, heating and shops. However, power plant systems are not typically directly connected to external networks; instead, office systems are more prone to attacks with smaller scale problems.

Some cyber security issues linked to lack of ***learning***. Some claimed that future energy solutions are very vulnerable to cyber-attacks (ES, NO, UK), while others see that many wind power and electric vehicle charging facilities have already learned about how to manage cyber security. Yet, small energy start-ups might not include cyber security issues into their operations (ES, FI). It was also mentioned that civil servants are not cyber experts, and industry sees cyber security regulations lagging everywhere.

Regarding ***social networks***, some interviews mentioned Computer Emergency Response Teams and other similar co-operations across countries and sectors to disseminate information on, prevent and monitor information security events (FI, NO). Yet, this happens simultaneously with new hackers emerging or existing ones improving their skills. Hackers were mentioned to be national or professional actors, with main national actors on top of the cyber threat reports being China and Russia.

5.1.5. Geopolitics

Changing geopolitical relations were mentioned in 26 interviews. This was described as the interrelationship between the decline of the high-carbon regime (see Section 4.2) and the emergence of the new low-carbon regime, where historical blocks and power positions related to energy are shifting.

The ***expectations*** outlined risks for new types of conflicts around critical materials (UK), and local impacts with potentially negative influences on the environment, health, and human security (FI). Some posed the question of what the new coercive energy instruments will be, connecting to critical materials and renewable energy technology. There are signs of future conflict around critical materials, supply chains and low-carbon technologies, and it is uncertain whether new systems will be formed around cooperating and trading or around competition. Developments in the Arctic create new expectations due to improved access to minerals (FI). Local/regional conflicts and unethical conduct are the expected security risks in the production of critical materials, creating environmental damage and human rights violations, such as child labour (FI); e.g., pertaining to cobalt production in the Republic of Congo. Yet, scaling solar energy in Africa and its trade with Europe may help Africa develop its societies to prevent migration, alleviate poverty and increase stability. Some also expected new geopolitical competition emerge around green hydrogen (UK).

The interviews revealed little on ***learning*** regarding geopolitics. Some noted that, while renewable energy is available everywhere, its utilisation depends on technology, and is likely to benefit countries that are well-organised and have high technological competences. It was noted that learning around zero-carbon transition may bring new opportunities to the Arctic, which may alleviate geopolitical tensions there.

Geopolitical questions are by definition focused on state ***actors and networks*** they form. While electricity is not transported in as risky geopolitical supply chains as hydrocarbons, the dependence on renewable energy technologies and the critical materials they require, raises China as one of the key actors (NO, UK). Chinese control over wind turbines and solar panel production is described as an industrial strategy that aims to achieve control over critical materials, catalysers, and key technologies. Trade conflicts between the United States (US) and China show that geopolitical contradictions will still prevail with accelerating renewable energy. The European Union (EU) joint electricity market pursuits are perceived as a process which will improve security within Europe, but a problem of dependence exists via large intercontinental power grids between Europe and North Africa.

5.1.6. Internal stability

Issues of internal stability within countries emerged in 19 interviews. They concerned mostly questions regarding declining high-carbon energy regimes (see Section 4.2). There were some ***expectations*** around the risk of tensions if new technology-created options in the electrification of transport or heating are not available to people from lower income groups (FI, UK). Thus, it is important to couple new technology acceleration with policies that increase social justice.

Increase in nationalist thinking was associated with plenty of domestic reserve capacity for electricity production, instead of relying on international energy markets. This was regarded as leading to higher electricity prices and unhealthy energy market structure, being contrary to new ***social network building*** around the energy transition.

Internal stability links somewhat to what could be called as socio-economic security (e.g., lack of energy poverty, social safety, and citizens' economic stability). Socio-economic security did not emerge as a clear theme in the interview analysis, but some elements of it were detected. For instance, energy poverty in Scotland is an important policy issue. This was perceived to increase in the short-term via niche expansion but also hold potential to reduce, if the transition also improves building energy efficiency, or, if Scotland did not have a common electricity pricing with the rest of the UK. More broadly, the issues identified under other security categories, such as electricity system operability or cyber security (and protection against attacks on energy infrastructure), affect the broader safety experienced by the society and its people. For instance, hydrogen production in Estonia and new technologies in Finland and Scotland were perceived to enable more stable socio-economic conditions, creating opportunities for new domestic growth areas. This is linked

Table 4
The impacts of the expansion of renewable energy and electrification on security from the perspective of expectations, learning and networking.

Security themes	Niche development/expansion Expectations	Learning	Social network building
Energy security	Improved self-sufficiency but concerns about reliability; availability & price of critical materials	New technical solutions improve security; strategies for critical materials; 'green arms race'	New kinds of network dependencies but also flexibility within regional grid communities
Defence	Micro-grids offer military operations more security; wind power broadly beneficial to national security	Opportunities via military R&D; learning has resolved conflicts between defence air surveillance and wind power	Networks between defence forces, grid operators, defence forces & ministries have enabled common understanding
Electricity system operability	Diversity views on the complexity (too risky vs. solvable)	Dependence on large universities & global companies for technical learning; "engineering challenge"; learning requirements for civil servants on resilience	New cross-border reliance on neighbouring countries via increasingly interconnected electricity networks
Cyber security	Some expect high cyber risks due to more complex systems, while others perceive lower risks due to decentralisation	Advanced learning on wind power and electric vehicles, but lack of learning by start-ups and civil servants (who are not cyber experts)	Emergence of professional & national actors (esp. China & Russia) as hackers; cyber security collaboration across sectors and countries
Geopolitics	New types of conflicts around critical materials, e.g. US-China relations as well as local impacts of mining on environment, health and human security	Renewable energy more likely to benefit countries with high technological competence and good organisational skills; new opportunities for the Arctic to alleviate tensions	Importance of China via critical materials; scaling up solar to improve Europe-Africa relations and peace; Arctic council's role in environmental protection
Internal stability	Tensions & fear of unrest if opportunities to benefit are unequal; opportunities for social justice. Expectations of new growth areas increasing positive security.	Awareness on energy poverty, policy measures for all levels of society	Contrary development to social network building based on national ideas that create over capacity.

to new expectations and learning around the niche expansion.

5.1.7. Summary

Table 4 summarises the findings on how niche expansion is expected to impact security. Table 5 shows how expert attention to issues differed between the countries, and Table 6 illustrates the same variation for different groups of experts: public administration, business, research, and political actors. Public administration actors identified the most improved security of supply from renewables expansion, while in all groups this was noted as a benefit. They also viewed more benefits than other actors via greening of defence. Business actors had a more positive stance on how cross-border electricity trade can improve security than other actors. This was not at the time addressed by politicians at all and only somewhat by other groups but has following the events of 2022 received more attention in public. Before 2022, politicians were the actors most aware about the dependencies to China via critical materials and technological components. This is another topic that has heightened in importance since 2022. The risk of wind power disturbance on air surveillance radars was most reported by public administration actors. It may be that this group is more aware of such matters than other actors due to confidentiality pertaining to national defence.

5.2. Decline of the hydrocarbon-based energy system

5.2.1. Energy security

Some public administration actors and researchers in Estonia and the UK perceived that the declining hydrocarbon regime will create a negative energy security threat to some hydrocarbon producing countries by increasing their import dependence, when their domestic resources diminish. This means that the ***skills and assets*** built around the hydrocarbon production and use will also diminish, while these kills – especially around offshore oil and gas – can be repurposed, for instance, in offshore wind power or green hydrogen developments. For other countries, fossil fuels have been easy to stockpile, so energy security takes a different form that requires ***unlearning and deep learning*** due to more diverse and complex structure of the new energy system**.** Oil supply chains include bottlenecks in conflict prone areas and gas supplies include a risk of explosion. Removing them have an immense positive effect locally on peoples' wellbeing and security but requires ***deinstitutionalisation*** following ***shifts in pressures*** in order to materialise. The way in which the decline of the hydrocarbon-based system is managed was regarded important for energy security (UK).

5.2.2. Defence

The defence and military sector are highly technology intensive and dependent on the established energy regime, i.e., oil and gas, to operate (ES). Defence forces and militaries are generally not pioneering in the energy transition due to priority given to efficient and safe operations (ES, FI, UK), except for the active role of the US military in renewable energy R&D. Generally, the energy transition is ***disrupting*** the dominant energy-related ***skills and assets*** of the defence sector and repurposing efforts are required – and some related R&D is already taking place. Significant ***unlearning and deep learning*** are required on how the military can operate without fossil fuels, and in extreme weather caused by climate change. Climate change also creates new insecurities, such as the risk of mass migration for example from Africa or the Asia-Pacific region, change in global politics and increased conflict between actors in instances of water and food supply disruptions, requiring unlearning the established ways around security and defence.

5.2.3. Electricity system operability

The interviewees did not explicitly discuss ***disrupting and repurposing skills and assets*** related to electricity system operability. Although, as discussed above, the system is expected to change significantly. However, potential ***unlearning and deep learning*** was detected, as new systems may not require balancing capacity similarly as old systems, which shifts thinking in how electricity systems operate. New electricity-based systems will involve ***deinstitutionalisation*** of old hydrocarbon-based structures, making them gradually redundant or substantially reconfigured based on shifting functions of the energy system and reducing consensus about the cultural importance of the hydrocarbon-based system. The former is connected to cyber security, a theme not visible in regime decline, other than the increase of criminal actions requiring increase in counteractions, as described above.

Table 5

Variation in experts' attention to security implications of renewables niche expansion per country (* = individual remarks (<15%, ** = medium attention 15–50%, *** = much attention (> 50%); + indicates positive security and – negative security).

Expanding niche	Estonia	Finland	Norway	Scotland/UK
Improved supply security (+)	large ***	large ***		medium**
Technically solvable issues with security benefits (+)	medium **	medium **		some *
Greening of defence (+)	medium **	some *		some*
Rising cross-border reliance which also improves security (+/-)		some *	some *	medium **
Arctic security (+/-)	some *	medium **	medium **	some *
Dependencies on technical components and critical materials (-)		medium **	medium **	large ***
New vulnerabilities (-)		some *	some *	medium **
Wind power disturbs defence radars (-)	large ***	medium **	some *	some *
Solutions developed for of wind power and radars, or not an issue (+)	medium **	medium **	some *	some *
Rising risk of grid disturbance (-)	medium **	some *		some *
More complex future system (-)		medium **	some *	some *

Table 6
Variation in experts' attention to security implications of renewables niche expansion per expert group (* = individual remarks (<15%, ** = medium attention 15–50%, *** = much attention (> 50%); + indicates positive security and – negative security).

Expanding niche	Public admin (n = 21)	Business (n = 9)	Research (n = 21)	Politics (n = 9)
Improved supply security (+)	large ***	medium **	medium **	medium**
Technically solvable issues with security benefits (+)	some *	some *	some *	medium **
Greening of defence (+)	medium **		some *	
Rising cross-border reliance which also improves security (+/-)	some *	medium **	some *	
Arctic security (+/-)	some *	some *	some *	medium **
Dependencies on technical components and critical materials (-)	medium **	some *	some *	large ***
New vulnerabilities (-)	some *	some *	some *	some *
Wind power disturbs defence radars (-)	large ***	some *	medium **	
Solutions developed for of wind power and radars, or not an issue (+)	medium **	some *	some *	medium **
Rising risk of grid disturbance (-)	medium **		some *	some *
More complex future system (-)	medium **		some *	medium **

5.2.4. Geopolitics

A key geopolitical implication of the energy transition is how large hydrocarbon-exporting countries, such as Russia, Saudi Arabia and Northern African states, will react (ES, FI, NO, UK) when their ***skills and assets are disrupted*** and whether they are able to repurpose them (cf. Mäkitie, 2020). The stranded assets of fossil fuel producing companies and countries are geopolitically significant (UK). Blue hydrogen was perceived as a potential opportunity to extend the economic security provided of the fossil fuel states, by revitalising the sector and making the negative economic impact of hydrocarbon phase out more gradual (NO, UK).

In the Arctic, climate change has caused polar ice to retreat which has opened opportunities for increased transportation routes between China, Europe and the US, and improved access to underwater oil and gas reserves. This has strengthened interest in maintaining the established hydrocarbon-based regime and counter the required ***unlearning*** processes in phasing out fossil fuels. It has also created new security risks via super states China, Russia and the US being interested in the Arctic area for geopolitical and economic reasons (FI, NO).

The above links to Russia as a key global actor that resists unlearning around the hydrocarbon economy (FI, NO, UK). The internal discourse and communication targeting the population in Russia was seen as built in a hydrocarbon culture and its energy superpower status with a strategy for producing more fossil fuels. The substantial political interest in Russia to maintain the current system due to the connections of the decision makers to hydrocarbon production was mentioned.

The past two decades saw a changing tone of discussions in EU-Russia energy relations to a more negative direction, partly related to a conflict between EU and Russia visions about the future energy system and Russian interference to EU politics. This indicated ***deinstitutionalisation*** and changing power-relations already prior to 2022. Also, disagreements between Russia and the US were seen to be difficult for Europe. The interviewees posed questions on how the decline of the hydrocarbon-based regime will be managed, due to its negative impact on the economic security of hydrocarbon producing countries, and how these countries will be supported, for instance, via ***repurposing of skills and assets*** and ***deep learning*** in the transition. A failure to do so leads to a disorderly transition considered a major security threat.

Reduced demand and prices for hydrocarbons may lead to global instability via cascading effects in terms of migration and escalating conflicts (FI, UK). Yet, some see the gradual ***deinstitutionalisation*** of the geopolitics of hydrocarbons, frequently used as a political lever, to be a positive effect on security (ES, FI, NO, UK), where the decarbonised world will probably be more peaceful, power decentralised and energy access more democratised (NO, FI).

The transition is also creating incoherence between climate policy and foreign policy administrations (UK). There is divergence between climate change mitigation and Western country foreign policies that fund hydrocarbon-projects, the latter requiring ***deinstitutionalisation*** to better support transitions. While some countries have planned to no longer fund hydrocarbon-increasing development projects, there were concerns that the recipient countries seek funding from China or Russia. The energy transition has foreign security and trade implications: while there is less dependence on other countries, co-dependent energy relationships prevent geopolitical conflicts and increase global stability. This has led to plans to update energy diplomacy in Europe, connected to ***unlearning and deep learning***.

5.2.5. Internal stability

Another key issue with the declining hydrocarbon-based regime is the risk of tensions and fear of unrest created between livelihoods based on fossil fuel production and climate change goals (ES, NO, UK), resulting from ***disrupting skills and assets***. Some view this risk as small when managed right (FI). Yet, Europe, for example, has a significant number of fossil fuel industry workers and transition will be costly with risk of unemployment and a reduced living standard even for countries such as Norway, if substantial reconfiguration opportunities do not exist. There is a risk that the oil and gas industries are not quick enough in retraining workers with the risk of unemployment (UK). A concrete example in Estonia is the location of oil shale production in an area that is more deprived and has a Russian speaking majority. It was perceived that phasing out oil shale may cause more unemployment and economic hardship, and Russia potentially aiming to stir up dissatisfaction and instability among the local population.

As a process to support ***unlearning and deep learning***, programmes for just transition (e.g., the EU Just Transition Mechanism and the Scottish Just Transition Commission) are implemented to alleviate tensions and create opportunities for ***repurposing skills***,

Table 7
The impacts of the hydrocarbon-based regime decline on security from the perspective of disruptions to and repurposing skills and assets, unlearning and deep learning, and deinstitutionalisation and shifting pressures.

	Regime decline processes		
Security themes	Disruptions to and repurposing skills & assets	Unlearning and deep learning	Deinstitutionalisation and shifting pressures
Energy security	Increasing energy import dependence in hydrocarbon producing countries	Unlearning stockpiling as key energy security measure and deep learning about new kind of energy security needed. Improvement of wellbeing by reducing oil and gas related conflicts and accidents	Energy independence; reducing ties between hydrocarbon exporters and importers
Defence	Dependence of military sector on oil and gas in its operations is either reduced or becomes isolated from rest of society	Unlearning and deep learning about how military operates without fossil fuels and in extreme weather caused by climate change	–
Electricity system operability	–	Potential unlearning and deep learning as new systems may not require balancing capacity similarly as old systems	Replacing or reconfiguring hydrocarbon networks and institutions with electricity-based networks and institutions
Cyber security	–	–	–
Geopolitics	Uncertainty regarding how hydrocarbon producing countries react to significant stranded assets	Updating energy diplomacy, but some countries (e.g. Russia) resist unlearning around the hydrocarbon economy; ice retreat creates opportunities for fossil exploration that counter unlearning and create new security risks due to increasing interest in the Arctic	Shifting power-relations between actors and incoherence between climate and foreign policy; but need to support hydrocarbon countries to maintain global stability
Internal stability	Tensions and fear of unrest resulting from unemployment and reduced living standards	Programmes of just transition to alleviate tensions, but also a lot of resistance to unlearning and deep learning	Increasing cultural juxtapositions in society, e.g. far-right and extinction rebellion

addressing labour union concerns regarding hydrocarbon phase-out and income differences in the transition, alongside investments in renewable energy industries (ES, NO, UK). Just transition is perceived important as, without support, there are possibilities for large unemployment leading to social unrest and political instability. In Norway, there are such strong ties between the country's socio-economic security and the hydrocarbon industry that the decline process is slow. A researcher interviewed stated, that, hydrocarbon decline would create a risk of mass unemployment and a loss of skills. In contrast, a business actor perceived that the wealth already generated by Norway would protect against such risks.

There is also resistance to ***unlearning***, linking to pressures working against ***deinstitutionalisation*** of the hydrocarbon regime and to political instability. It was viewed that many political far-right parties are working to save fossil fuel industries and oppose climate change mitigation (ES, FI). In general, those that make political use of social disruptions to further their political aspirations via populism cause a risk. These forces are facing citizen protests for climate change, which may create further tensions in society.

5.2.6. Summary

Table 7 summarises the security considerations under regime decline processes. Table 8 shows how expert attention to issues differed between the countries. Table 9 shows how security implications varied based on the actor type. In general, public administration actors and researchers seemed more aware or concerned of the security implications of hydrocarbon regime decline than business actors and politicians. While business actors mentioned fewer categories of security implications, they saw most security risks from the energy transition to EU relations with Russia and did not mention positive security impacts in the context of decline. Public administration actors most frequently mentioned tensions and unrest from fossil fuel job decline and positive impacts on peace and democracy. Politicians most often noted the positive effects of the fossil fuel regime decline on improving climate security.

6. Discussion

We conducted a thematic analysis of 60 interviews with energy, security, defence and foreign policy experts, based in four European countries, regarding the security implications of the energy transition. We then combined this with analytical categories based on the transitions literature. We used the conceptualisations of niche development/expansion and regime decline, proposing three sub-processes based on literature to characterise the latter: *disruptions to and repurposing skills and assets, unlearning and deep learning,* and *deinstitutionalisation and shifting pressures*. We used these concepts in a new sense, not focusing on how transitions unfold more broadly, but how these processes connect to negative and positive security. Our analysis shows that, similarly to socio-technical transitions themselves, also their security implications comprise both technological and social aspects which are intertwined.

Essentially, the socio-technical energy regime is shifting to one built around a more complicated and digital system. Our analysis shows that the expectations regarding the security effects of this shift differ. Positive effects relate to improved supply security, resilience, and decentralisation. Negative effects connect to hydrocarbon producing countries and new vulnerabilities due to intermittent renewable energy and cyber risks. Despite the European energy crisis in 2022, following the war by initiated by Russia in Ukraine, many expectations outlined in this analysis continue to be valid. In contrast to 2020–2021, the security expectations are now much more openly discussed in politics and in the media than before and are frequently heightened in importance (e.g., critical materials and Europe's dependencies on China). The European Commission has openly communicated about the positive security benefits of the zero-carbon energy transition in its RePowerEU policy package (EC, 2022a). The reactions of Russia specifically to the European energy transition are no longer a security concern as such, because of the war already started. However, the crisis was a substantial 'landscape shock' to the energy sector which may further accelerate the energy transition. At the same time, it has denoted a turn in European political focus (back) to geopolitical security of supply more generally (Kuzemko et al., 2022) with a risk of energy policy subsumed under military and economic goals of the state, linked to energy sovereignty of the old world of traditional fossil fuels (Żuk and Żuk, 2022).

The realisation of the expectations, illustrated in this study, depends on the development of interactions between state and non-state actors. Energy companies are mostly private (with some public ownership), while both the decarbonisation and energy security policy objectives require state interventions. The above developments hinge on, for instance, whether mutually dependent cross-border grid communities become common (Blondeel et al., 2021; Scholten et al., 2020) and on the actions and support given to

Table 8
Variation in experts' attention to security implications of hydrocarbon regime decline per country (* = individual remarks (<15%, ** = medium attention 15–50%, *** = much attention (> 50%); + indicates positive security and – negative security).

	Estonia	Finland	Norway	Scotland/UK
Declining regime				
Fossil fuel countries increased import dependence (-)	some *	some *		some *
Uncertainty about hydrocarbon countries' reactions (-)	some *	some *	some *	some *
Worsening relations with Russia (-)		medium **	some *	medium **
Militaries dependence on hydrocarbon regimes (-)	some *		some *	some *
Tensions and unrest related to reduced employment (-)	large ***		some *	medium **
Global instability (-)		some *		medium **
Reduced political leverage of fossil energy (+)	some *	some *	some *	some *
Peace, democracy and access (+)	some *	some *	medium **	some *
Improved climate security (+)	some *	some *		some *

Table 9
Variation in experts' attention to security implications of hydrocarbon regime decline per actor group (* = individual remarks (<15%, ** = medium attention 15–50%, *** = much attention (> 50%); + indicates positive security and – negative security).

	Public admin (n = 21)	Business (n = 9)	Research (n = 21)	Politics (n = 9)
Declining regime				
Fossil fuel countries increased import dependence (-)	some *		some *	
Uncertainty about hydrocarbon countries' reactions (-)	some *	some *	some *	
Worsening relations with Russia (-)	some *	medium **	some *	some *
Militaries dependence on hydrocarbon regimes (-)	some *			
Tensions and unrest related to reduced employment (-)	medium **	some *	medium **	some *
Global instability (-)	some *		some *	some *
Reduced political leverage of fossil energy (+)	some *		some *	some *
Peace, democracy and access (+)	medium **		some *	medium **
Improved climate security (+)			some *	medium **

hydrocarbon exporting countries (Tynkkynen, 2019; Vakulchuk et al., 2020). There are substantial plans in the EU, for instance, to strengthen the cross-border electricity transmission infrastructure (EC, 2023), and the events of 2022 showed that crises can strengthen this kind of collaboration (EC, 2022b). The realisation of expectations is also affected by country specific contexts and perceptions about energy and security, demonstrated by a lack of fully uniform expectations by experts in the four countries.

Estonian experts paid little attention to new dependencies (e.g., critical materials) and system complexity resulting from the transition. This may be explained by an earlier state of transition than in other countries, or the foreseen synergies from synchronisation with the European electricity grid. Finnish experts saw technological solutions to complexity problems facing the grid or the expansion of wind power, while attention to geopolitics or internal consequences of hydrocarbon decline was small. This links to a purposeful disconnect of energy policy from security policy prior to 2022 (Kivimaa, 2022) and the dominance of techno-economic knowledge (Höysniemi, 2022). Unlike other countries, Norwegian experts did not discuss security of supply concerns due to Norway being a fully energy independent country, and also the global perspective was rather small. This emphasis has now changed also in Norway (Energikomisjon, 2023). The Scottish/UK experts were most informed about a range of security-related consequences, taking a global perspective. This is perhaps partly explained by the UK's colonial past.

While in 2020 and 2021 the experts discussed the use of hydrocarbons as political leverage in international relations, i.e., 'an energy weapon' (cf. Smith Stegen, 2011), they perceived military action unlikely. The 2022 events shifted these perceptions almost everywhere and made geopolitics a part of the EU member states' and other European states' energy security discussions. In addition, the explosions in the Nord Stream pipelines visibly brought the protection of energy infrastructure against physical attacks on the policy agenda when most attention had before been on hybrid attacks. The energy crisis also showed how the impacts of the war cascaded into countries not directly dependent on Russian energy due to the international nature of the energy markets and potentially profit-seeking activities of major energy producers.

Effectively, the 2022 developments had important implications for the geopolitics of energy, where the expansion of renewable energy and electrification are in the process of creating a new geopolitical model, well visible in, for instance, EU energy policy. This geopolitical model, however, needs also to be increasingly connected to social safety and security, and to the aims to deliver a just transition alongside affordable, accessible, and environmentally sustainable energy for all. Social security means, besides the government policy objective, a freedom from constant economic insecurity and sufficient finance for basic needs (Żuk, 2023). This is not an easy task, given regional differences in European countries and elsewhere in the world. Nevertheless, it is increasingly important to address, because a lack of social security, especially in more deprived regions, is likely to increase resistance to low-carbon energy transitions.

6.1. Security implications of the energy transition from the perspective of niche development/expansion and regime decline

The following will discuss how the specific processes under niche development/expansion and regime decline, in the context of their security implications, are interconnected, drawing examples from our analysis. The analysis suggests that *learning* about new more complex energy systems and creating solutions to its security risks is coupled with regime actors' *unlearning* their assumptions and practices around the established energy system and deep learning about the changing system dynamics vis-à-vis shifting *system pressures*. Thus, the processes are complementary in advancing the energy transition. Yet, a security (and transitions) related risk for this is created by the countertrends to *unlearning* by some incumbent actors. Our analysis illustrated an example of such resistance to *unlearning* through the developments in the Arctic and Russia to increase hydrocarbon exploration. Such developments also exist elsewhere on the globe. These countertrends may strengthen the initially destabilised energy regime and are connected to questions of economic or geopolitical power of those countries.

Security also connects *learning* in transitions to large, institutionalised actors, such as universities, globally operating companies, and militaries. Given the complexity of new energy systems and niche technologies, R&D by such actors is paramount, and make other actors dependent on them – interconnecting with the process of *building social networks* and *unlearning and deep learning* by the militaries. In essence, the important role of these actors also shows that some large incumbents have the needed skills and capabilities that complex transitions require and cannot be fully held by new niche actors. This places emphasis on *repurposing skills and assets* and who has access to these skills and assets. *Learning* dynamics of transitions are also important with respect to knowledge transfer and support towards hydrocarbon producing countries to maintain global stability. The complexity of new digital energy systems also places new *learning* and *unlearning* requirements to public civil servants who may have little expertise in issues such as cyber security.

The *building of new social networks* and *deinstitutionalisation and shifting pressures* are also related but differently, creating contradictions rather than complementarity. Our findings show that *new social networks* between state actors improve information exchange, system flexibility, reaching a common understanding, economic collaboration, and peace building (i.e., contribute to positive security). In turn, *deinstitutionalisation and shifting pressures of* hydrocarbon-based systems, while improving energy security, may create risks of global instability, if the old partners are left stranded. For instance, deinstitutionalisation of international relations and foreign policy-based structures may lead to escalating conflicts between states, if those experiencing transition negatively are not supported.

The *expectations* around niche expansion also connect with *disruption to and repurposing skills and assets* around regime decline. Our analysis showed that *expectations* around the security implications of renewables expansion are polarised: more or less secure future energy systems. The polarisation of expectations is a similar result to earlier studies (Mata Pérez et al., 2019; Szulecki and Kusznir, 2018). The expectations on renewables expansion emphasised the risk of new types of conflicts, which may become greater if combined with conflicts around hydrocarbon decline. The latter depend on how hydrocarbon producing countries, or people in those countries, react when the needs for their skills and assets built for the hydrocarbon economy are *disrupted* and what are the opportunities for *repurposing*.

In the context of security and energy transitions, we see also how *expectations* for niche development may link to *deinstitutionalisation and shifting* pressures: differing visions for the future are more likely to lead to the reduction of cultural consensus and need to be reformulated by getting previously established actors to renew their operations by *repurposing skills and assets* rather than objecting to change. Such disagreement on future expectations is more likely if *unlearning and deep learning* are not taking place or are too focused on nationalist thinking instead of international collaboration. In contrast, if *expectations* for niche development are coupled with *unlearning* in regime decline, the result may create positive security via improving peace, democracy and just transitions. To achieve this, deinstitutionalisation coupled with new network formation and repurposing skills and assets is necessary for many actors. Energy justice (Sovacool et al., 2019) and energy diplomacy may be important mechanisms to merge the different processes in a supportive way. Based on the above discussion we argue that the sub-processes of niche development/expansion and regime decline are integrally connected in sustainability transitions and need more conceptual and empirical research.

Overall, negative security was emphasised more than positive security in the expectations of actors. Finnish experts were the most positive and Norwegian the least positive about improved security of renewables expansion. This may not correlate directly with the level of risk but with the lack of attention so far on conceptualising the positive aspects of transitions in security terms. This calls for more research in how positive security in terms of freedom of insecurity, emancipation (Booth, 2007) and empowerment of communities (Gjørv, 2012) could be connected to research on just transitions.

7. Conclusions

We examined the negative and positive security implications of the unfolding energy transition and identified six themes that intertwine with technological and social effects. These include (1) energy security, (2) defence, (3) electricity system operability, (4) cyber security, (5) geopolitics, and (6) internal stability. We also analysed how the security issues played out in the context of niche development/expansion and regime decline processes, drawing from transition studies. We proposed a new typology of regime decline processes: disruption to and repurposing skills and assets, unlearning and deep learning, and deinstitutionalisation and shifting pressures.

Our findings showed that the security implications of energy transitions extend beyond traditional energy security concerns (i.e., security of fuel supply and technical system reliability) and intertwine with questions of national defence, global security and justice, and local and regional developments. From the perspective of sustainability transitions, it is important to note that transition and security developments related to (renewables) niche development/expansion are at least partly dependent on how (hydrocarbon) regime decline occurs and is managed. This is likely to differ across country contexts. Learning and unlearning as well as new social network building and deinstitutionalisation can lead to complementary processes in the best case. However, transitions may be hindered, and negative security implications occur, if disruption to and repurposing skills and assets are not properly accounted for and supported, and the countertrend to unlearning addressed. This means unlearning some of the old energy security practices and creating a new model that deals with broader security, environmental sustainability, and societal justice concerns of the transitioning energy systems all at once. This will be an important but difficult task – faced with the risks of securitising energy and support for old world hydrocarbon-based thinking. The recent more open discussion about energy, transitions and security may, however, support a positive outcome.

Our research highlights several avenues for future research. These include new empirical research, especially systematic foresight studies, on security in the context of energy transitions. Also, the relationship between national energy and security administrations calls for more research, in addressing not only the geopolitical but also local and human security questions. For sustainability transitions research, our suggested typology of socio-technical regime decline processes and their interplay with niche expansion processes requires further conceptualisation and empirical evidence. The insights provided were based on interviews in selected European countries which show diversity in how security in the context of energy transitions is perceived. Alternative countries, such as those that have been more heavily dependent on Russian natural gas imports, such as Germany, might provide additional insights. Moreover, future research should generate insights also from the perspective of Global South actors; those that are currently dependent on hydrocarbon exports or otherwise lacking the political decision-making and needed resources to decarbonise the energy sector. In addition, the perspective of regions or localities with specific interest regarding energy resources, such as the Arctic, could be explored in more detail.

For policy development we conclude that policymakers across domains should pay attention to the learning and network dynamics around the energy transitions and their security implications: nationally, regionally and globally. They should consider the effects of learning and the formation of new energy networks on the reactions of powerful hydrocarbon exporters, and how to support the hydrocarbon producing companies, regions and states with their unlearning and reskilling processes. Some of the negative security implications of the energy transition can be alleviated with attention to social justice, within cities, nations, regions and globally. Locally and nationally, the formation of new networks across energy and security sectors and advancing digital and cyber expertise is needed.

Data statement

The study used confidential interviews as data. For more information contact the authors.

Declaration of Competing Interest

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

Data availability

The data that has been used is confidential.

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