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A socio-technical lens on security in sustainability transitions: Future expectations for positive and negative security

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ABSTRACT

A transition to net-zero carbon energy systems, imperative to combat climate change, is unfolding around the world. Other socio-technical systems also face the need to transition to become more environmentally and socially sustainable. We argue that such transitions will have both positive and negative security implications on numerous issues which deserve attention but have been little addressed in transition studies. We take a socio-technical lens and propose that these security implications can be ex-ante analysed via three elements of socio-technical systems: technology, actors, and institutions. We provide an illustration of such analysis in the energy transition context and use this to create a categorisation framework for expectations analysis. Regarding the technology dimension, expectations concerning, e.g., resource and technology dependencies, risk for technical system disruptions, and effects on interconnected systems can be analysed as relevant security issues. For the actor dimension, issues such as geopolitical uncertainties, regional (in)stability, internal tensions, and diffusion of power are identified. For institutions, e.g., influence on democratic institutions, peace building and structural violence can be assessed. We argue there is a need for improved and forward-looking policy coordination across domains and for academic studies that utilise foresight approaches to assess different security expectations more concretely.

1. Introduction

A transition to net-zero carbon energy systems is unfolding around the world, with broad implications for security. Generation from wind and solar is increasing, facilitated by the growing use of electricity, interconnected grids, and digital technologies. The global energy transition is frequently described in terms of fossil fuel (oil, coal and gas) phase-out (Green, 2018), and decentralisation of

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energy infrastructure (Alstone et al., 2015). This implies significant changes in energy use and in the ownership of vital energy resources and assets, including decreased fuel import dependence, increasing local energy production and autonomy, and the decline of traditional utilities (Seba, 2014). We also see a rise in large centralised renewable energy facilities as incumbent energy companies attempt to diversify, and as new companies enter the market. These developments are important for addressing climate change but have many knock-on effects within and beyond the socio-technical energy system, with implications for the environment, international trade and cooperation, employment and livelihoods, and security. Thus, visions for energy system futures based on such holistic transitions are more complex than single technology-based visions, involving broad changes in economic relationships and regulatory frameworks (Groves et al., 2021), which also tie into security considerations.

Besides energy, other socio-technical systems also face the need to transition to become more environmentally and socially sustainable. In this article, we argue that such sustainability transitions will have both positive and negative security implications (defined below) on numerous issues which deserve attention. Yet, security has been little addressed in sustainability transition studies. Here, we take a socio-technical lens from sustainability transitions research (e.g., Köhler et al., 2019) and propose that expectations concerning these security implications can be ex-ante analysed via three core elements of socio-technical systems - technology, actors, and institutions – as essential parts of transitions. We provide an illustration of such an analysis in the energy transition context and use this to derive a categorisation framework for ex-ante expectations analysis.

We define security as low probability of (potential) harm, or the preservation of 'acquired values' (e.g., territorial integrity, human survival, sustainability), wherein the nation state is not the only entity to be secured; individual, social, and international systems, and humanity at large can also be treated as referent objects, i.e., entities threatened and to be protected (Baldwin, 1997). In turn, sustainability transitions are defined by social issues, such as changes in employment, fulfilment of basic needs, and the price of commodities. For example, there are aspirations for the global energy transition to improve energy justice by reducing energy poverty, advancing access to energy, and compensating employment losses in regions invested in coal mining and oil refining (Burke & Stephens, 2017). These types of outcomes have *positive security* (Gjørv, 2012) implications, whereby they contribute to better lives and livelihoods. However, these outcomes are not self-evident. Wide-reaching distributional, social, and economic implications mean that sustainability transitions are also intertwined with potential *negative security* implications (see Section 2). Thus, we ask 'What kind of expectations for the future have been constructed around the positive and negative security implications of sustainability transitions?' The question we pose implies that there is no definite account of the positive and negative future effects of transitions on security, but rather differing expectations regarding the future. We illustrate an analysis responding to this question in the context of transitioning to renewable-energy-based electricity systems.

The changing geopolitics of renewable energy and related political, economic, and military aspects have received much interest recently (Goldthau et al., 2019; Scholten, 2018; Scholten et al., 2020; Vakulchuk et al., 2020). However, there lacks a broad account of how the various security aspects of energy systems will shape, and be shaped by, renewable energy transitions. There are of course different pathways to zero-carbon energy systems. For example, nuclear power provides an alternative pathway. This pathway has a different set of security-related implications which are not explored in our illustration.[1]

Our illustration focuses mostly on state-level security aspects, while it also touches upon other referent objects, such as individuals. We investigate the expectations that have been presented in literature around positive and negative security implications of the energy transition and explore the dynamics of the emerging system and its implications for the phase-out of the incumbent system. This approach has been described elsewhere as a whole systems approach (Blondeel et al., 2021).

Methodologically for our illustration we undertook an integrative review, which can be conducted to address emerging topics that "benefit from holistic conceptualisation and synthesis of the literature to date", leading to initial conceptualisations (Torraco, 2005, p. 357). We adopted a broad search approach, utilising the research databases Scopus and Google Scholar for academic literature. We also searched for relevant reports from the webpages of security research organisations, think tanks, government departments and research projects. This approach reflects the emerging nature of security studies in the context of the energy transition, where much relevant information continues to be published in the form of 'grey' reports and scientific studies. Our review was not exhaustive, but rather aimed at providing a view on the diversity of expectations around the possible future impacts of energy transitions on security.

Section 2 conceptualises and defines security for our purposes. Section 3 introduces the socio-technical approach to be used as a frame and context for the security expectations analysis. Section 4 illustrates an analysis of positive and negative security expectations in the energy transition context, using the socio-technical components of technology, actors and institutions. Section 5 discusses the illustration and derives a categorisation of security elements under each of our socio-technical dimensions to be used in ex-ante expectations analyses and other studies on the security impacts of sustainability transitions. Section 6 concludes.

2. Conceptualising security

Security means different things to different people. The concept and practice of security have evolved over time. In simple terms, security means the absence of threats (Booth, 1991) or the absence of threats to acquired values (Wolfers, 1952). These values have been interpreted, for example, as territorial integrity, political autonomy, economic progress, global health or even ecological stability (Baldwin, 1997; Barnett, 2001; Feldbaum et al., 2006; Sovacool & Saunders, 2014). Peoples and Vaughan-Williams (2014) argue that security is a 'derivative concept'; different worldviews give rise to different conceptions. While some may consider certain conceptions

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[1] For example, security links to nuclear power have been made in terms of human and environmental security (Szulecki & Kusznir, 2018), the risk of terrorist attacks (Li et al., 2012) and connections between civic and military nuclear power (Johnstone & Stirling, 2020).

of security, such as 'national security', as universal values, others adopt more nuanced and contextual views, allowing for the concept to change over time.

The transformation of security over time is, in particular, attributed to the apparently changed realities of the post-Cold War scenario. Security studies have begun to show greater signs of broadening and deepening of the security agenda. For instance, the Copenhagen School has introduced five sectors of security: military, environmental, economic, political, and societal (Buzan et al., 1998). Similarly, security studies have become more attuned to the need for expanding the scope of 'referent objects' (whom to protect), such as individuals (Jones, 1999). Security now means more than just military power and encompasses approaches that go beyond traditional state-centrism. This also gives rise to newer conceptions of security, which are acknowledged by intergovernmental processes. For example, the United Nations Development Programme (UNDP) released a human development report in 1994 that reinforced the paradigm of 'human security', bringing forth notions of 'freedom from fear' and 'freedom from want'. It also sought to expand the meaning of security to include seven dimensions: economic, food, health, environmental, personal, political, and community (UNDP, 1994).

A redefinition of security has, therefore, paved the way for a more nuanced understanding of the security implications of processes and phenomena in varied contexts, across different scales, and involving different actors. Security may be expressed in terms of geopolitics, through the lens of inter-state relations, in the form of conflict or cooperation. It may also be contextualised in sub-national settings in terms of both 'structural' and 'direct' violence. This includes the context of the security-development nexus, as also reflected in the 1994 human development report (Acharya, 2001). Structural violence refers to "preventable harm or damage to persons (and by extension to things) where there is no actor committing the violence or where it is not practical to search for the actor(s); such violence emerges from the unequal distribution of power and resources or, in other words, is said to be built into the structure(s)" (Weigert, 2008, p. 2004) or institutions.

To provide conceptual coherence to the widening field of security, Buzan et al. (1998) proposed 'securitisation' as a framework that highlights how issues are transferred discursively to the security sphere. Excessive securitisation may have unfavourable consequences for society, implying that issues move beyond the reach of democratic politics and become subject to exceptional measures (Buzan et al., 1998). When it comes to new challenges such as globalisation, digitalisation and climate change, the distinction between normal and security politics is not necessarily so strict. According to some scholars, the security sector may also need to adopt new practices by engaging with other fields, rather than merely imposing security measures on new areas (Oels, 2012; Trombetta, 2008).

The concepts of negative and positive security can be correlated with sustainability transitions and security. Gjørv (2012) argues that "negative security can be understood as 'security from' (a threat) and positive security as 'security to' or enabling." Hence, negative security is understood as the 'absence' of a threat, while positive security is regarded as the 'presence' of conditions that further human well-being. True or complete security requires more than just the absence of threats (Booth, 1991). Normatively, while negative security is associated with "non-democratic emergency processes and state-centric threat/defence thinking" (Nyman, 2016), positive security is often linked with justice, and non-violent measures (Gjørv, 2012). As argued by Nyman (2016), rather than going into the ethical debate of whether security is good or bad, or categorise it as 'from' and 'to', the value of security should be hinged on contextualism, pragmatism, and reflexivity. The meaning and value of security differs according to the empirical context: actors, processes, practices, consequences, and experiences. Therefore, negative and positive security do not necessarily function as a "binary", but as a "scale". We use the typology of 'positive' and 'negative' security to reflect these debates – with negative security denoting 'insecurities' (threats posed by the sustainability transition) and positive security signifying enablers of peace, stability, and well-being (by ways supported by the sustainability transition).

2.1. *Energy security*

Pertaining to our illustration, energy security has been defined as low vulnerability of vital energy systems (Cherp & Jewell, 2014), referring to the absence of threats to system operations; state capabilities for threat response (Jewell & Brutschin, 2019); or the ability to ensure availability and affordability of energy supplies (IEA, 2022). This approach to energy security is focused on security of supply within states, including the availability, affordability, accessibility, and acceptability of energy (Cherp & Jewell, 2014). It focuses on how vulnerable energy systems are, and not necessarily on broader security implications and other actors beyond the state. Interactions concerning these other actors have the potential to impede necessary transitions, and create unforeseen security concerns, if not adequately considered.

An extensive corpus of literature has discussed energy security with reference to fossil fuels. These analyses have often formulated rather narrow definitions, such as "the continuity of energy supplies relative to demand" (Winzer, 2012, p. 36). Some studies have developed more nuanced definitions. For example, Sovacool and Mukherjee (2011) describe energy security as "a complex goal involving questions about how to equitably provide available, affordable, reliable, efficient, environmentally benign, properly governed and socially acceptable energy services". Energy security has somewhat been discussed in connection to energy transitions, with the expansion of renewable energy seen as either contributing to or distracting from energy security (e.g. Szulecki & Kusznir, 2018), and how these divergent perceptions of energy security lead to a differentiated pace of energy transitions in different countries (Mata Pérez et al., 2019).

3. Socio-technical approach to sustainability transitions

Research on socio-technical systems originates from different strands of academic literature, including technological regimes, systems of innovation, sociology of technology and institutional theory (e.g. Geels & Schot, 2007; Kemp et al., 1998). There are

Table 1
The multi-level perspective in the energy system context.

Component	Description	Examples in the context of energy transitions
Landscape	An external environment that influences interaction between niche(s) and regime (Geels, 2011), which is a slow-moving and relatively stable political, economic and institutional context (Berkhout et al., 2009).	Climate change impacts and global climate agreements; digitalisation and cyber security risks; developments in geopolitics and international relations; Covid-19 pandemic; political and economic actions of major states, such as China, the United States and Russia; economic growth targets that privilege continued hydrocarbon development.
Regime	'Deep structure', i.e., the semi-coherent set of rules that guide the activities of actors that associate with the socio-technical system (Geels, 2011), e.g., market structure and user preferences, industry structure, policy and politics and symbolic meanings constructed around the system's technology and infrastructure (Ghosh et al., 2021).	Energy production/consumption technologies, grid infrastructure, market structure for power and heat, supply chains of fuels and energy technology, energy market and safety regulations, environmental standards, emissions trading systems, climate and energy policy and politics, meanings associated by energy industry employees and citizens with different sources of energy production.
Niche	Niches are protected spaces, e.g., innovation labs, small markets or geographical areas that support innovations that significantly deviate from the established regime (Geels, 2011).	Innovation programmes for new sustainable energy technologies (e.g., energy storage, wave-energy); public procurement for new energy efficiency services; niche markets for biogas vehicles, feed-in tariff programmes to support renewable energy uptake.

Table 2
Components of socio-technical systems.

Component	Definition	Examples in the context of energy transitions
Technologies	Material (or virtual) artifacts and knowledge. Technology can range from minor technical components to an entire economic sector; in sustainability transitions studies, technology is typically addressed "with respect to a function embedded in a reasonably complex focal product", e.g., wind power technology refers to "a wind turbine that converts wind to electricity" (Andersson et al., 2021, p. 113).	Energy technologies (e.g., nuclear power plants, wind turbines), energy infrastructure (e.g., network of power plants), technology and infrastructure for energy supply and trade (e.g., electricity grids, gas pipelines), and knowledge about the energy system. In energy transition, technologies such as wind and solar farms aid the transition from fossil fuels to a decarbonised system.
Actors	Networks or individuals, including private actors, firms, governments, organisations, collective actors, etc. Here, we distinguish actors from institutions by focusing on specific **actions** of the actors that contribute to positive or negative security and we include states as actors rather than as institutions.	Energy producers, distribution and transmission network operators, public agencies and officials for energy production and supply, energy users (industry, commerce, citizens). In addition, governments and militaries, and their actions impacting energy transitions and security.
Institutions	Formal or informal rules, regulations, standards, and social or procedural norms. Here, institutions are regarded as the (semi-) permanent social or policy **installations or configurations formed by groups of actors**.	Regulations for energy production and supply, international agreements on climate change, international organisations, agreed practices. In addition, informal institutions, such as structural violence or child labour in connection to the mining of hydrocarbons, minerals or metals.

different frameworks in socio-technical transition studies. The most popular have explored the dynamics of change on multiple levels (e.g. Geels, 2004), how different processes support the development of innovation niches (e.g. Kemp et al., 1998), the emergence of new technologically oriented innovation systems (e.g. Hekkert et al., 2007) and the management of transitions (e.g. Loorbach et al., 2015).

The socio-technical approach is focused on 'sustainability transitions', namely processes by which change occurs in socio-technical systems towards improved environmental (and social) sustainability. One of the most frequently used frameworks, the multilevel perspective (MLP), provides a heuristic to help explain how such transitions can occur with the introduction of new niche technologies and business models that, together with changing contexts (at the 'landscape' level), cause pressure to change the prevailing socio-technical systems (also referred to as 'regimes') (Geels, 2020) (Table 1).

The different approaches in sustainability transition studies, going beyond the MLP, share the idea that technological change is intertwined with social change. The speed and nature of technological change is impacted by social elements, especially actors and their interactions in networks, as well as informal and formal rules and institutions. Thus, our conceptualisation of transitions for the analysis of their potential security implications focuses on 'technologies', 'actors' and 'institutions'. These components not only shape the current sustainability transitions but have important connections to security. Table 2 summarises how these components have been defined and examined in the literature on sustainability transitions.

Transitions research traces disruptive technological pathways through a pre-development phase, followed by acceleration and the eventual stabilisation of the new regime (Kanger & Schot, 2016; Rotmans et al., 2001). Some security threats may not be present when the transition is in the pre-development or acceleration phase but become more substantial and visible when a new socio-technical regime has materialised.

4. Illustration: using the socio-technical lens to analyse the security implications of sustainability transitions in the context of energy

In the following, we analyse expectations regarding the potential positive and negative security implications of the global energy transition, based on an integration of views across the academic literature. Merging the socio-technical approach with insights from literatures on energy transitions and international relations, we will next discuss how security implications of energy transitions connect to (1) technology, (2) actors and (3) institutions.

4.1. Technology

Technological changes are at the heart of reducing old or creating new system vulnerabilities. From a technological perspective, the expected security implications of energy transitions connect largely to energy security and the safety and reliability of the increasingly electrified and, to some degree, decentralised energy system. While often discussed as part of state-level decision making, international interconnections of electricity and gas networks and energy trade mean that many security implications of the energy transition are likely to have cascading effects across states.

4.1.1. Positive security

In the future, electricity systems are increasingly expected to be interconnected via large international 'super-grids'. As energy systems electrify and hydrocarbons are phased out, some have argued that these super grids can increase security of supply because the long-distance shipping of hydrocarbons and related disruptions will be reduced (Scholten, 2018). Further, others anticipate that super-grids help create regional grid communities between countries, which reduces the need for back-up reserves (Blondeel et al., 2021; Scholten et al., 2020). This highlights the link between technological change and new institutions for improved security.

The future development of renewables such as wind and solar is expected to yield new opportunities to use a far wider variety of energy resources (Vakulchuk et al., 2020). This is anticipated to improve energy security especially in countries that have been reliant on imports of hydrocarbons. Decentralised energy systems based on renewable energy have the potential to secure access to affordable clean energy in rural or remote regions, where centralised supplies are unaffordable to local populations, and where citizens generally seek more autonomy and involvement in energy systems (Alstone et al., 2015).

Further, decentralisation of energy infrastructure via renewables is foreseen to create opportunities to reduce the magnitude of harm during extreme weather events or hybrid-attacks if electricity networks are divided into micro-networks that can temporarily operate autonomously off-grid (e.g. IEC, 2014). A move away from large, centralised production means that any disruption to a single production facility, whether due to environmental or human factors, impacts fewer people (Lu et al., 2016). Moreover, alternative peer-to-peer energy networks can increase grid reliability, provided that sufficient user data is available (Groves et al., 2021).

The effect of the transition on the reliability of energy systems is mostly seen as a problem that has technological solutions. For example, data from the US suggests that increasing net-generation from wind and solar photovoltaics initially leads to larger disruptions in power service, but the duration of disruptions decreases as the net-generation from these sources increases (Harker Steele et al., 2021). In Europe, modelling-based studies indicate that combining flexible generation (e.g., hydropower and biomass), network interconnections and energy storage is expected to lead to reliable, affordable and sustainable electricity systems (Child et al., 2019).

4.1.2. Negative security

Renewable energy based systems are expected to create new dependencies on critical materials and renewable energy technology, when these systems upscale (Lee et al., 2020; Øverland, 2019). For example, wind turbines and electric vehicle battery production depend on rare earth materials (e.g., aluminium, copper, lithium and magnets) (IEA, 2021). The importance, and cost, of elements required for the generation of batteries and renewable energy infrastructure is anticipated to grow (Kalantzakos, 2020; Paltsev, 2016), with lithium especially critical (Greim et al., 2020). Some analysts suggest that disruptions in production and delayed investments caused by the COVID-19 crisis may further imperil efforts to secure the supply of critical resources (IEA, 2020).

Recent research argues that the scale and scope of security challenges from critical materials supply is still unknown (Lee et al., 2020), linking to the overall scarcity and concentration of mineral resources globally (Kappenthuler & Seeger, 2019). Some claim that the anticipated risks regarding critical materials "may not materialise 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). Power lines, patents, energy storage technology and dispatch will also become key factors (Paltsev, 2016). Actors that control them will have leverage on others and may even exclude them or delay their energy transition.

More complicated and interlinked electricity systems may lead to new system vulnerabilities, including increased potential for cyber-attacks (Cornell, 2019). "[C]onflict will increasingly be organised around networks and nodes of information transfer", including attacks on both civilian and military networked computer systems such as smart grids (Peoples & Vaughan-Williams, 2014, p. 187). As the energy transition is associated with growing reliance on ICT and digital devices as part of smart grids, the threat of cyber-attacks on critical energy infrastructures is growing; electricity distribution is particularly vulnerable to such attacks (Onyeji et al., 2014). More distributed and decentralised technologies increase the "surface area" exposed to attacks (Cornell, 2019). This signifies a shift in landscape pressures for energy systems with cyber-attacks as a new security threat (Kivimaa & Sivonen, 2021).

As energy is a precondition for other sectors of society to operate, risks pertaining to the operation of the energy system will cascade to other sectors, such as the finance system, heath care, food and water supply, logistics, and fire and rescue services. For example, land-use related decarbonisation efforts, such as increasing the use of agro-biofuels in energy production, have adverse impacts on food and water security (Popp et al., 2014).

4.1.3. Summary

From the technological perspective, the positive security expectations concerning the global energy transition relate primarily to improved security of supply via less reliance on fossil fuels, more diverse energy source bases, and international electricity grid communities reducing the need for reserve capacity. In addition, decentralisation of energy systems is expected to reduce the magnitude of impact from external shocks to the systems, such as extreme weather or hybrid attacks – while the reliability of system operation is to be safeguarded with flexible generation, network interconnections and the development of energy storage. In turn, negative security expectations relate to security of supply risks of critical minerals and metals used in new energy technologies and of the technologies themselves, to cyber security threats, and the magnitude of negative security events via cascades into other sectors.

4.2. Actors

Actors are closely linked to technologies, since it is actors who mediate the design and use of new technologies, the resources that technology production and use require, and associated services. A technological transition that disrupts traditional business models and actor-networks (Johnstone et al., 2020) can act as a source or alleviator of geopolitical tensions between states, or as a source of peace or conflict based on how individual actors (e.g., citizens, trade unions, other organised groups) react to it. Energy is a strategic good that government actors need to secure through diplomatic, economic and military means (Siddi, 2019). The energy transition has also already introduced new resources with high priority in strategic competitions between actors.

4.2.1. Positive security

Hydrocarbon supply and demand patterns have been key factors influencing global geopolitics (Paltsev, 2016; Sauvageot, 2020; Scholten et al., 2020). The energy transition is anticipated to break this locked-in reliance on fossil fuels and reduce geopolitical risks to many states from those hydrocarbon-producing states who have used energy as a coercive instrument in international relations (Blondeel et al., 2021). This also means that more countries are foreseen as energy exporting participants in global energy markets, with production from renewables and energy relations between states becoming more regional (Scholten et al., 2020). Renewable energy based systems are expected to decrease the number of large conflicts between countries and regions, with reduced resource scarcity and improved security of supply (Vakulchuk et al., 2020). The development of hydrogen technologies could also redraw the geography of energy trade and reshape geopolitical relations through the creation of a new class of energy exporters (Van de Graaf et al., 2020).

In many parts of the world, climate change is seen increasingly by defence administrations and militaries as a security threat with growing implications for their energy policies (Jayaram & Brisbois, 2021). Defence planning in many countries, such as the UK, the US and India, shows that militaries are starting to break the hydrocarbon lock-in, improving energy efficiency and adopting renewable energy (Jayaram, 2020; Samaras et al., 2019). Militaries are increasingly bound by governments' climate change commitments. For instance, the UK's Ministry of Defence released a Climate Change and Sustainability Strategic Approach in 2021 that refers to the need for the UK military to contribute to the net-zero target for 2050, and "harness the potential of" the more cost-effective, and secure clean technologies (UK Ministry of Defence, 2021). The North Atlantic Treaty Organisation (NATO), with its continued emphasis on energy security, has also published reports and strategies regarding the adoption of green technologies to reduce carbon footprint and their vulnerabilities (NATO, 2020).

As energy production is decentralised and most countries become both producers and consumers of energy, entrenched patterns around actor-networks and business models are expected to shift and political power become more diffuse (Scholten & Bosman, 2016). Pertaining to individual actors, the energy transition offers many citizens an opportunity to produce and store the electricity and heat they need and contribute to overall electricity supply and stability (Koirala et al., 2016). These outcomes are hoped to improve energy justice and the democratic quality of energy systems (Szulecki & Overland, 2020). The ideas of just transitions (Jenkins et al., 2016) and energy democracy (Burke & Stephens, 2017) are hoped to reduce conflicts and help address existing social inequalities (Szulecki & Overland, 2020).

4.2.2. Negative security

Those state actors that fail to adjust to the advancing energy transition risk a weaker geopolitical position. Eventually, as hydrocarbons are phased out, power is anticipated to shift from hydrocarbon owners to actors that control zero-carbon solutions, manage related strategic infrastructure (e.g., high voltage transmission lines), and possess critical mineral resources (Paltsev, 2016; Scholten et al., 2020). However, the specific outcomes of these shifts will depend on the capacity of various actors to respond and adapt to the transition. It is uncertain how large hydrocarbon-producing countries will react, which creates risks for regional or global stability (Scholten et al., 2020).

States that rely on revenues from hydrocarbon exports, such as Saudi Arabia, Russia, Venezuela, and Nigeria will eventually face serious economic losses (Paltsev, 2016). This might have broader geopolitical implications, especially for countries like Russia, whose global leverage has greatly relied on hydrocarbon production (Romanova, 2021; Scholten et al., 2020; Tynkkynen, 2019). In some relations, such as between the EU and Russia, shared interests in hydrocarbon trade helped maintain a balance between the parties (Scholten et al., 2020), which the European energy transition was expected to destabilise (Romanova, 2021) prior to Russia invading Ukraine in 2022. Some foresaw a great threat from Russia to rely on military means instead of energy as an instrument of power in international relations, when energy transition would progress (Tynkkynen, 2019). However, this risk materialised already in 2022 when Europe was still heavily dependent on Russian fossil fuels, accelerating the energy transition.

Dependencies on critical materials will result in a new configuration of actors and supply networks. Critical materials are an issue of concern to technology developers and national security planners (Criekemans, 2018). This intertwines with the supply of renewable energy technologies and their components. The cost and availability of technologies, such as high-purity polysilicon for photovoltaics, are dependent on global supply chains and leading manufacturing countries (Sandor et al., 2018). China is a major player in this market due to its rich mineral supplies and associated requirements for companies to use those minerals in production in China and involving Chinese companies (Criekemans, 2018; Freeman, 2018). This also includes the supply of renewable energy technologies. Some studies argue that the risk of geopolitical conflict over critical materials for renewable energy is limited (Øverland, 2019). Yet, in 2010, China stopped REE exports to Japan amidst tensions over the disputed Senkaku/Diaoyu islands in the East China Sea (Schmid, 2019). A similar scenario is also envisaged with the current geopolitical tensions between China and the US, which are already entangled in a trade and technological 'war' (Smith, 2021).

The energy transition may have direct implications for the operation of the military sector. Being among the main global carbon emitters, militaries largely depend on incumbent hydrocarbon-based systems (Belcher et al., 2020). Both military equipment (tanks, transport vehicles, planes, naval vessels, missile systems) and logistics structures are heavily reliant on, and major consumers of fossil fuels.

The phase-out of hydrocarbons may also increase internal conflicts within countries, with focus on individuals as referent objects for security. For example, Algeria is highly dependent on hydrocarbon trade. As Europe moves away from hydrocarbons, this dependence is expected to create environmental and social conflicts and higher levels of out-migration (Desmidt, 2021). In parts of Europe, right-wing populism has already created civil unrest around energy transitions (Vihma et al., 2021). Research suggests that right-wing populist parties and their supporters in Europe and Anglophone countries are more hostile to renewable energy and carbon-taxes (Lockwood, 2018). Increasing renewable energy and coal phase-out have created cultural, ideological and political problems. In Poland, for example, right-wing political parties oppose the energy transition in a verbally aggressive way using an 'ideological veil' to defend particular political interests (Żuk & Szulecki, 2020). The degree of conflict in regions and in communities facing the pressure to phase out hydrocarbons is likely to depend on cultural issues and how conflict is managed proactively via 'just transitions'.

4.2.3. Summary

The actor perspective on security emphasises changing relationships between state actors, but also individuals. At state-level, positive security impacts are expected to break states' reliance on other hydrocarbon producing states, reduce conflicts between states, and create opportunities for more states to be energy exporters. For militaries, renewable energy transition may improve climate security. At the individual level, control over energy is expected to diffuse with individual citizens gaining opportunities to produce their own energy and participate in the energy system in a more democratic way. Negative security impacts relate to potential risks for global stability and unanticipated negative reactions when hydrocarbon producing states become weaker, dependence of other countries on China for sourcing of critical materials, and risk of internal conflicts caused both by worsening living conditions in hydrocarbon exporting states, as well as increasing opposition from right-wing populists to climate change mitigation.

4.3. Institutions

The energy transition shapes existing institutions and creates new ones, which also affects security. For example, the International Energy Agency (IEA), established in 1974 to address security of supply and markets for oil, now has a mission to "shape a secure and sustainable energy future for all".[2] The International Renewable Energy Agency (IRENA) was created in 2009 to advance the energy transition and it has explored the geopolitics of renewables (IRENA, 2019). Institutions comprise public policy and regulatory structures, formal market structures, and informal structures constructed around socio-technical systems – everything that constitutes as 'rules' of the regime.

4.3.1. Positive security

With a changing societal landscape, new intra-state security considerations emerge, altering informal and formal institutions around energy systems. Renewable energy can create new institutional arrangements and reshape existing institutions. For example, foreign policy institutions can be altered with the help of renewable energy to facilitate cooperation and peacebuilding between countries in regions such as South and Central Asia, and in conflict areas (Bellini, 2018; Edwards, 2018; Huda, 2020). Bellini (2018), for instance, highlights the role of Energy Peace Partners, a US-based (private) start-up, in implementing solar energy schemes in conflict areas, which helps secure camps and protected areas with assured energy access through renewable energy powered generators, and by reducing their dependence on conflict-afflicted local fuel supply chains. Bertram and Beck (2015) argue that the energy transition has a 'green peace dividend' because of energy independence, mitigation of climate security threats, and avoidance of limited resources strengthening corrupt governments.

In international development cooperation/policy, energy transitions are often seen through the lens of 'energy democracy' (cf. Burke & Stephens, 2017). Energy democracy can be consistent with promoting peace instead of competition/conflict by restructuring the energy sector, and its associated institutions. This involves empowering communities to participate in energy systems, redistributing economic and political power locally, and strengthening democratic participation (Burke & Stephens, 2017), thereby, reducing structural violence and aiding peacebuilding (Edwards, 2018). For example, in Nepal, which has been affected by a decade-long civil war, micro-hydropower projects have served as tools of environmental peacebuilding by both international (e.g., United Nations Development Programme) and national institutions (e.g., Nepal Electricity Authority and District Development

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[2] https://www.iea.org/about/mission.

Committees), as they bring socioeconomic changes by providing electricity, rural livelihoods, food security, and economic opportunities (Krampe, 2018).

Energy transitions are touted as the most important climate security solution with wide-ranging implications for domestic and international policy institutions (Looney, 2016). In many developing countries, such as Mexico (von Lüpke & Well, 2020) and India (Pillai & Dubash, 2021), the push towards energy transitions has paved the way for stronger climate institutions due to the co-benefits associated with renewable energy: climate action and energy security (Pillai & Dubash, 2021). From a fragmented policy response due to divisions between climate, energy, and other relevant institutions, these countries have moved gradually towards creating synergies between different institutions, albeit challenges still exist (von Lüpke & Well, 2020). At the international level, the launch of initiatives such as the 'Green Grids Initiative: One Sun One World One Grid' at the 2021 Glasgow Summit (jointly by India and the UK) also points towards the role of energy transitions in providing teeth to future climate action and climate transformation through existing and new institutions and harmonisation between domestic and international institutions. Beyond climate institutions, energy transitions have also become a cornerstone of other institutional mechanisms, such as those dealing with human health and air quality, as they are deemed critical to resilient health systems and health security (Neira, 2020).

4.3.2. *Negative security*

Climate change is linked with violent conflicts as a 'threat multiplier' (Barnett & Adger, 2007). The energy transition, although a partial reliever of these conflicts, may also worsen them. Formal and informal institutional rules driving economic growth in the Global North already undermine stability in parts of the Global South, for example, through internal conflicts related to oil and gas in South Sudan and Nigeria (Bestoyin, 2018). The energy transition may simply shift the location of conflicts to countries with cobalt and other rare earth minerals required for the energy transition. It may feed into harmful societal structures and increase inequality or polarisation between actors within countries, thereby exacerbating local conflicts and structural violence, such as worsening poverty, discrimination or marginalisation (Karlsson & Zimmer, 2020). For example, cobalt mining in Congo shows negative security impacts via informal institutional structures, such as violent conflicts, unsafe livelihoods, health and security risks for miners, and entrapment of women and young children (Sovacool, 2019).

There may be unintended consequences of low-carbon energy transitions in conflict-prone regions, requiring conflict-sensitive policies (Dabelko et al., 2013). Such consequences may, for example, include the strengthening of undemocratic institutions, and criminal and armed groups, in countries that are known to be rich in coltan and lithium and are excessively dependent on high-value resource exports (Vandeveer, 2013). Also elsewhere, while the energy transition offers potential to improve social outcomes from energy institutions, potential cascading effects may reinforce entrenched patterns around gender, geographic and demographic disparities (e.g., in job creation in the clean energy industry) (Carley & Konisky, 2020).

Energy production is anticipated to create new intra-state security threats via land use. Renewable energy production requires more surface area than hydrocarbons, creating socio-political conflicts in countries with strong private property rights (Klass, 2011), and exacerbating land grabbing-associated conflicts in places where land claims are more tenuous (Scheidel & Sorman, 2012). For example, in India, land acquisition for large-scale solar power projects have already led to disagreements between the government and rural communities. Landless pastoralists and agriculturalists belonging to marginalised communities are pushing against these projects legally, with the result that many of them are being downscaled (Chari & Shaikh, 2020).

The energy transition is also expected to pose threats to social stability (Mirumachi et al., 2020). For example, large-scale shifts in how labour markets and employment have been organised in coal, oil and gas production regions can spur civil unrest (linking to the actor dimension); this depends on the extent to which transitions are perceived to be 'just' (de Jong et al., 2017) and the new institutional mechanisms created to enable just transitions. Inadequately planned and poorly legitimised climate policy may accentuate societal inequalities, contributing to the rise of populist movements (Schaller & Carius, 2019). Populism can increase the threat to social stability, with increasing confrontations between people for, or against, low-carbon action. 'Just transition' policies and institutional structures may help alleviate these challenges and promote job creation, job upgrading, social justice and poverty eradication via new practices and business models (Piggot et al., 2019).

4.3.3. *Summary*

From the institutional perspective, positive security implications of energy transitions comprise strengthening of foreign policies for peace building and of development policies to empowering local communities with help of renewable energy. Energy transitions can also pave way for stronger climate institutions. Negative security links to risks of worsening conflicts in some areas or shifting location of conflicts and structural violence from hydrocarbon localities to localities with rare earths, with unintended effects on strengthening undemocratic institutions. In addition, institutions in the Global North may undermine stability in the Global South via the ways in which it pursues the energy transition.

5. Discussion

5.1. *Summarising the energy transition illustration*

We have summarised in Table 3 the above discussed positive and negative security expectations of energy transitions and how they connect to technology, actors and institutions comprising the socio-technical system. If realised, these security implications have potentially cascading effects to other socio-technical systems such as food, land-use and employment, and the international and national security systems. Negative security shows new threats arising from critical minerals and metals and the cyber space

Table 3
Expectations around positive and negative security of energy transitions.

Potential negative security implications	Potential positive security implications
Technology	
– New dependencies on critical minerals and metals, and components of renewable energy technology – Increased risk of cyber attacks – Adverse impacts to other systems, e.g., water and food security	– Larger variety of resources and reduced reliance on fossil fuels leading to improved security of energy supply – International grid communities reducing the need for reserve capacity – Reduced magnitude of impact from disruptions caused by weather shocks or hybrid attacks because of more flexible and decentralised system
Actors	
– Uncertain reactions of hydrocarbon producing states, with risk of global instability – New instabilities between some regions, e.g., Europe and Russia – China's dominance over critical material supply – Risk of internal conflicts in hydrocarbon states via worsening economic conditions – Adverse short-to-medium term impacts to the operation of militaries – Heightened risk of disruption from right-wing populists	– Reduced reliance of states on hydrocarbon producing states, reduced conflicts between states, and new energy exporters – Improved climate security – More diffused power, citizens gaining more control over energy production
Institutions	
– Institutional rules driving economic growth in the Global North already undermine stability in parts of the Global South – problems shift from hydrocarbons to rare earth elements – Unintended strengthening of undemocratic institutions, and criminal and armed groups, in countries rich in rare earths – New land-use related conflicts around renewable energy	– Improving peace building in foreign policy and reduced dependence on corrupt governments with help of renewable energy – Reducing structural violence by empowering communities and diffusing power – Emergence of new players who may be able to break the conflict trap and aid existing processes (e.g., peace operations) – Support for new climate institutions

(technology), risk of conflict and instability arising from hydrocarbon phase-out (actors), and unintended strengthening of undemocratic institutions and land-use issues (institutions). Positive security implications 'enable' improved security of supply via a large range of resources and improved resilience (technology), more diffused power, opportunities for energy justice and improved climate security (actors), and improved peace building and reduced structural violence (institutions).

The changes in security concerning the energy sector have important policy implications. The technological perspective shows a need for new risk analyses for the energy policy domain, in connection with data, food and water policy. The actor perspective emphasises the importance of foreign and security policy as well as internal affairs and regional policies in addressing the security implications of energy transitions by reducing conflicts and alleviating the negative consequences of energy transitions globally and locally. Finally, the institutional perspective shows important connections to employment, social and land-use policies, because the way these policies address energy transitions is important for achieving just transitions. In sum, the socio-technical lens on the security expectations of energy transitions shows the need for improved and forward-looking policy coordination that encompasses not only energy, climate, environment and security policies but also domains relevant for societal stability and wellbeing, namely development, employment and educational policies.

5.2. *Towards a new framework for analysing security in the context of sustainability transitions*

As sustainability transitions progress in real life, and new policy frameworks – such as the European Green Deal – increasingly support such transitions, there is a growing need to create ways in which the positive and negative security implications of large-scale transitions can be predicted and alternative futures assessed. This is important so that public policies can be based on good information and policymakers can prepare for different outcomes, reducing negative security risks and enabling positive security. Drawing from our efforts to combine security studies' knowledge with sustainability transitions research, and the illustrative analysis of the energy transition, we create a categorisation framework for the ex-ante analysis of security expectations concerning transitions, organised under the three socio-technical components (Fig. 1). Further, these impacts can be assessed for different stages of the transition: predevelopment, acceleration, and stabilisation (cf. Kanger & Schot, 2016).

The newly emerging research on security in sustainability transitions (Johnstone & McLeish, 2020; Johnstone et al., 2017; Kivimaa & Sivonen, 2021) shows important connections to research on the power and politics of transitions (Avelino, 2021; Langhelle et al., 2019) that should be explored further. As sustainability transitions progress, moving from niche development to regime destabilisation, there will be an increasing need to learn how ensuing technological risks, tensions and conflicts in actor-relations and institutional changes impact on multiple domains. Further, environmental challenges can cascade as security risks via environmental disasters. Zero-carbon transitions alleviate some of these risks, but with new ones potentially created, for example, in relation to mining critical materials.

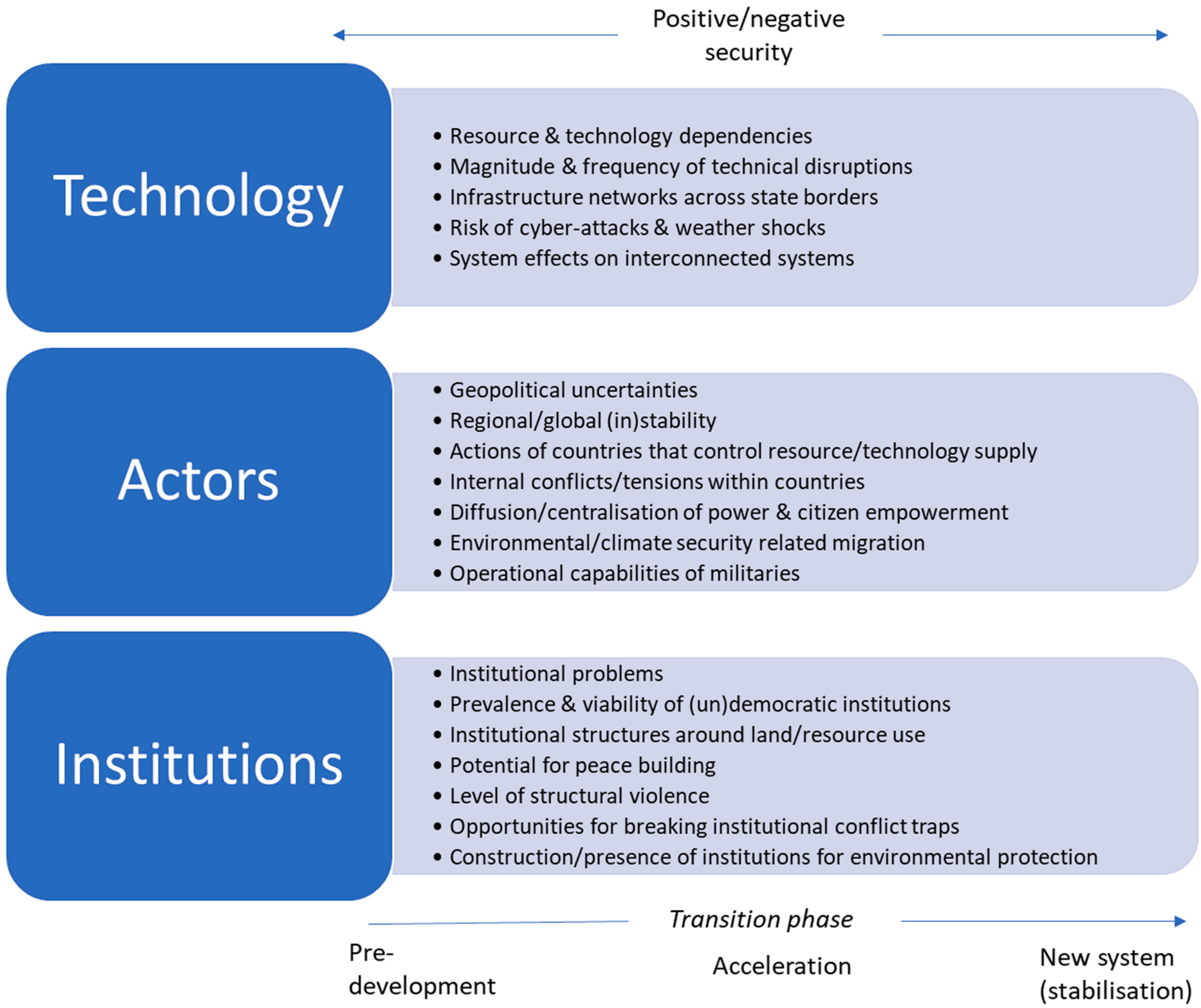

Fig. 1. Framework for analysing security expectations concerning sustainability transitions. The elements under technology, actors and institutions are examined in terms of change/influence towards positive or negative security and can be assessed for each phase of the transition.

6. Conclusions

This paper argues that academic research needs to examine the potential security implications of sustainability transitions more systematically. We used a socio-technical lens to propose how to analyse different security expectations around transitions and illustrated this in the context of energy transitions. These expectations for the future demonstrate diversity and uncertainty regarding how positive and negative security implications unfold. We argue that further research is needed, using futures studies methodologies, to gain insights into which security implications from sustainability transitions (e.g., in energy, transport, food, industry) are more or less likely and which scenarios or contexts, as well as what factors, play a role in advancing positive security. For the sustainability transitions field, this study emphasises the need for further research on the interconnections between local and global developments around technologies, actors and institutions in transitions, including studies on different empirical domains of transitions research, such as health or agro-food.

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