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A Resource Curse for Renewables? Conflict and Cooperation in the Renewable Energy Sector

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Abstract:

Previous studies have shown that fossil energy systems can be a conflict objective, means or cause. This study explores how renewable energy (RE) systems can interact with conflicts and to what extent the risk of different conflicts may change. Renewable resources, in contrast to conventional fossil resources, are more difficult to control in time and space. RE systems depend on exploiting flows rather than extracting stocks, are geographically more evenly distributed, and the energy density is lower. As a consequence, economic and geopolitical incentives for states to engage in conflicts to secure or control RE resources are low. However, increased competition for land increases the risk of local conflicts that involve non-state actors, since it can reduce actor's ecological space. Distribution and use of RE can be designed to have a low risk of interacting with conflicts, but the success of this depends on the technologies implemented and other sustainability policies. Increased dependence on control systems used to manage variable electricity production increase exposure to cyber threats while as small-scale distributed generation reduce incentives to attack the system since such systems are less sensitive to attacks.

Keywords: Energy security, Conflict, Renewable energy, Security

1. Introduction

Energy resources and supply chains are reported to increase the risk of conflicts through a variety of relationships [1]. For example, power struggles can arise when actors disagree on who should control and access globally scarce but locally abundant resources. The literature on energy conflicts mainly addresses non-renewable resources such as oil [2, 3] and natural gas [4]. A likely explanation for this research focus is that fossil fuels currently occupy a substantially larger share of the global energy mix. This may change for a number of reasons, e.g. climate change mitigation policies that favour renewable energy and efficiency improvements.

Renewable energy is often advocated as a means to mitigate climate change and strengthen energy security [5-7]. Previous studies have shown that in the longer term, the policy fields of climate change mitigation and energy security are mainly synergistic [8, 9]. This is partly because renewable resources are more evenly distributed geographically than fossil resources and mitigation measures often entail increased energy efficiency. However, such studies frame the energy system as a referent object, i.e. some feature of it, such as reliability of energy services, is the object to secure. Another perspective, not commonly adopted for renewable energy, is to frame the energy system as a security subject.[1] In the security subject perspective the energy system can enhance insecurity, e.g. exacerbate conflicts, or enable security, e.g. facilitate cooperation and capacity development[2].

Johansson [12] conceptualised and assessed the relationship between renewable energy and security. Some studies have also analysed specific connections between increased use of renewables and conflicts, for example the risk of a renewable energy weapon [13], the risk of

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[1] Johansson [10] proposed that interpretations of the relationship between energy and security can be classified as belonging to either when the system is exposed to threats, commonly known as security of supply or security of demand, or when the system is causing and generating insecurity, for example caused by a perceived political or economic value.

[2] Security can be approached as negative, i.e. studying threats to security, or positive, i.e. studying what enables security [11].

a renewable resource curse [14], the co-evolution of global low-carbon energy systems and interstate collaboration [15], interactions between biofuels and food riots [16] and conflicts related to increased competition for land [17, 18]. However, there have been no systematic assessments of how a transition to renewable energy system can reduce, or increase, different types of conflicts, since previous studies have tended to focus on a narrow range of conflicts [19]. A research overview published in this journal noted the sparse literature on how the risk of conflicts differs for depletable and non-depletable resources [20]. This study sought to fill that gap by testing a previously developed framework on the most significant renewable energy systems (see below).

There are several options available that would make energy systems more sustainable. The International Energy Agency’s (IEA) 2014 edition of the World Energy Outlook provided a scenario of how global energy systems could develop and be compatible with the 2 degree climate target (the 450 parts per million (ppm) scenario) [21]. The scenario involves a strong increase in renewable energy, enhanced efficiency and a decline in oil and coal use compared with the base year 2012. The four largest renewable sources in 2040 are bioenergy (106 exajoules (EJ), up from 56 EJ), hydropower (25 EJ, up from 13 EJ), wind power (18 EJ, up from 2 EJ) and solar photovoltaic (PV) power (7 EJ, up from 0.3 EJ). Bioenergy is depicted in the scenario as a versatile resource and is used within electricity generation (27 EJ), industry (16 EJ), transport (20 EJ) and buildings (37 EJ). Other studies have shown varieties of this energy mix as a result of different assumptions on the availability of resources and cost of resources and technology [21-25]. In all these studies, a major proportion of the increased supply of renewable resources comes from bioenergy as a primary source of energy and/or electricity from wind, solar PV and hydro. Therefore, these options were chosen as objects of the present analysis.

Energy systems can have different relationships with conflicts and these conflicts can differ in severity. Using a previously described framework [1], this study analysed three relationships. First, when the energy system is an objective in the conflict, this group includes geopolitically and economically motivated conflicts in which the conflicting parties have diverging opinions on who should access energy resources and/or control the energy system [26, 27]. Second, when the energy system is a means that is used in a conflict, i.e. the conflict does not have to be about energy but e.g. energy can be used as a weapon [28] or intentional attacks on the energy system can be used to harm or threaten an actor [29]. Third, when the energy system is the cause of conflict or catalyses its outbreak, e.g. local abundance of resources can be used to fund rebels in civil wars [30], environmental degradation from the production and use of energy can exacerbate ecological conflicts [31] and increased food and energy costs can give rise to social instability and riots [32].

The remainder of this article is structured as follows. Section 2 presents the framework and describes characteristics of different energy system stages that affect the risk of conflict, such as geographical concentration of primary resources. Section 3 analyses the extent to which these characteristics differ among renewable energy systems and compared to fossil energy systems. Section 4 summarises and discusses conflicts with low and high risks in renewable energy systems. The study shows that as a result of low geographical concentration and low energy density the risk of renewable energy to become an objective in interstate conflict is low. Renewable energy resources, particularly bio-resources, have a local environmental impact that can contribute to local instability and cause conflicts. Large-scale renewable electricity systems provide incentives for interstate cooperation through grid and market integration. However, such electricity systems are as exposed as centralised fossil systems to physical attacks. Moreover, together with increased dependence on control systems used to manage variable production, centralised electricity systems increase the exposure to cyber threats that would enable these systems to be used as a means in conflict. Lastly, section 5 provides some final remarks.

2. Theoretical background: Energy systems and conflicts

This study was of an explorative nature and used a conceptual framework [1] to analyse whether and how an expansion of renewable energy can result in structural changes in energy systems that affect the risk of conflict. A theoretical background to the selection of these characteristics can be found in that study. The framework provides examples of characteristics of the entire socio-technical energy system, i.e. from primary resource to final energy use (see Table 1), which when interacting with contextual conditions increase the risk of conflict. The entire energy supply chain was analysed here, since it is necessary to understand several supply steps in order to understand the risk of conflict. For example, it is not sufficient to only analyse resources if the aim is to understand the risk of 'resource conflicts', since the risk is also affected by international markets and institutions, and end use.

Table 1. Summary of energy supply chain characteristics analysed in this study.

Part of energy system	Primary resources	International trade	Conversion and Distribution	End use
Characteristic adopted in this study to assess the risk of conflict	Geographical concentration of resources, power density Entry barriers to production Land use and environmental pressure	Diversity of exporters Interdependence between exporter and importer	Energy density of chokepoints System topology/ systemic risk Symbolism of the system	Substitutability and flexibility of use Energy cost

2.1 Primary resources

This category covers characteristics of primary resources, such as biomass, that increase the risk of conflicts. Previous studies have claimed that the risk of conflict can increase if the geographical distribution of the resource is asymmetrical, i.e. when in relative terms resources are abundant locally but scarce globally. Local abundance can incite violent interstate competition for resources and is a prerequisite for the 'resource curse' [1]. The opposite situation, local scarcity of (renewable) resources, increases the risk of ecological conflicts.

Studies that depart from realism or geopolitics have concluded that competition for strategic resources or those that are a basic good (i.e. vital for the production of a large number of commodities) can trigger violent interstate conflicts where the objective is to secure access to resources [26, 33-35].

In addition, extraction of resources provides a stream of revenue and excess profits in places of local resource abundance (i.e. an area where plenty of the resource can be extracted below the market price). States that have an abundance of resources can develop less diversified economies, a part of the resource curse known as the "Dutch disease", since revenues from export of resources increase the currency exchange rate and make other sectors less competitive [36]. The economic rent-seeking can foster social instability, particularly if the stream of revenue deteriorates [37]. Social and political instability can also be a result of excessive rents that enable authoritarianism and low democratic accountability [38]. In failed states, belligerents can use resource rents to fund their organisations, which can affect the onset and duration of a violent conflict if entry barriers for production are low [30, 39].

The utilisation of energy resources can also degrade the natural environment and displace local communities as their livelihood is negatively affected. This can impose stress on societies and act as a ‘threat multiplier’ or ‘conflict catalyst’ [40, 41].

2.2 International trade

This category comprises characteristics of international trade in energy resources and carriers that affect the risk of conflict. This study analysed the diversity of international energy exporters and the power asymmetry between exporters and importers.

A more diverse international energy market with a higher number of exporters is likely to be more difficult to control and less attractive as a conflict objective. Access to such functioning markets also reduces the incentive to use force to secure upstream supply of energy. Studies departing from realism, (critical) geopolitics and Marxism have claimed that control of strategic international resource flows can be an objective for an interstate conflict [26, 27, 42]. These studies assume that the connection between power and resource control is embedded in the political economy of a centralised energy system.

Having control of the energy supply chain enables the controller to use the energy system as a means in a conflict. For example, it is possible for exporters to restrict flows (i.e. the ‘energy weapon’), or threaten to do so, for extortion of the weaker party and to gain leverage in political disputes [13]. However, the effectiveness of this behaviour has been questioned on the grounds that the states targeted seldom acquiesce [43]. Another option for the exporter is to subsidise energy bills below the market price in return for political loyalty of the importer. This can result in a high dependence in the importer, as the capital stock is distorted to a low energy cost. The exporter can then threaten to remove the subsidies if the importer does not concede on its terms. The incentive to use the energy weapon is low if international markets are liquid and diverse in terms of exporters and importers. Studies departing from liberalism assume that if trade partners are interdependent and both gains from trade, the most likely outcome is collaboration rather than conflict.[3]

2.3 Conversion and distribution

This category contains energy conversion facilities, such as refineries, and distribution of energy carriers (note that for electricity this includes both high voltage transmission and the medium/low voltage distribution grid). Energy systems can be targets of intentional attacks performed by terrorists or hostile states. Concerning terrorist attacks, this requires that the system's properties make an attack feasible, that the consequence of the attack is severe for those the attackers want to harm (but not for the attackers' supporters) and that the attackers are motivated to select the specific energy system, e.g. as a result of what it symbolises [45]. It should be noted here that the number of reported terrorist attacks on energy systems is rather low and those that have occurred to date were mainly in a handful of domestically unstable countries [45]. However, the number of attacks has increased over the past three decades [46].

Attack feasibility has historically been associated with single components that have a high energy density such as pipelines and electricity transmission grids with concentrated energy flows [29, 47]. Transmission grids can also enable failures to cascade and amplify, since their components (i.e. nodes and edges) are interdependent and the grid must be balanced at all times. Distributed generation is, therefore, less sensitive than a centralised system [48]. The increased use of computer systems to control energy systems can increase the systemic risk by permitting remote cyber-attacks on software by states or skilled non-state actors [49] (systemic risk is the risk of a system collapse, see [50]).

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[3] Realism assumes that states seek relative advantage while as liberalism assume absolute advantage, i.e. mutual gains are possible [44].

2.4 End use

Characteristics of energy use influence whether energy is perceived to be a strategic good and whether certain energy carriers are vital for the functioning and stability of society. A perception of good as strategic can motivate the use of force to secure access, i.e. when energy is an objective in a conflict. Dependence on vital goods makes societies vulnerable to disturbances, which enables hostile actors to use energy systems as a conflict means since a physical or economic disturbance can cause instability [1]. The electricity system is especially important, since other critical infrastructure is dependent on it (according to Rinaldi et al. [51] these are physical, cyber, geographical and logical relationships). These relationships were not analysed in the present study, as it was assumed that a transition to a renewable energy system would not alter the fact that the electricity system is critical infrastructure on which other sectors depend.

The transport and military sectors have a high dependence on oil products, which contributes to the perception of oil as a strategic resource. A higher flexibility of demand reduces incentives to secure access to energy and can reduce the risk of resource conflicts since certain energy carriers become less strategic. Flexibility is here approximated from end users’ flexibility to shift between fuels or modes of transport.

Energy is vital for the functionality of the society because of energy’s characteristics as a basic good, i.e. it supports the metabolism of societies. Constrained physical access to energy or a cost increase that makes it unaffordable can put stress on societies [52]. Previous studies have found that declining levels of affordability of transport fuels, but less so for electricity, can trigger social unrest in developing countries with low adaptive capacity [53, 54]. The cost of energy is therefore an interesting topic to study. High energy prices tend to affect food prices, which can affect food security – an issue that has been linked to violent food riots in societies with insufficient adaptive capacity [55, 56].

3. How can renewable energy systems interact with conflicts?

3.1 Primary resources

Three issues need to be addressed when assessing whether and how renewable resources risk contributing to conflicts. These are: 1) whether there is a geographically asymmetric distribution, i.e. resources are locally abundant but globally scarce, so that the resource is perceived as strategic and something worth fighting for; 2) whether there are low entry barriers that make it easy to extract the resource, so that a large set of actors can utilise the resource and receive a certain stream of revenue; and 3) whether utilisation of the resource has a high environmental impact that causes ecological conflicts.

The literature provides a wide range of estimates of the biomass potential available for energy purposes. Moriarty and Honnery [57] found estimates of technical gross potential in the range of 27-1500 EJ/yr, in addition to current supply. However, the viability of the higher end of this range has been questioned in several regards, including constraints such as land degradation, diminishing returns on marginal land, land use for food production and biophysical limits to net primary production [57-59].

The IPCC estimated potential annual production of biomass for energy purposes by 2050 to be 100-300 EJ, with a technical upper boundary at 500 EJ/yr [60]. The global energy assessment (GEA) estimated the global theoretical potential of biomass to be 160-270 EJ/yr, distributed across different regions [25]. Erb et al. [61] estimated the global primary crop potential in 2050 to be 77EJ/yr and provided an uncertainty range of 26-141EJ/yr that depended on assumptions for yields, diets and political stability in production regions.

Although they provide a lower range than GEA they too concluded that the available land stretches over large areas but that due to favourable climate conditions two large regions, sub-Saharan Africa and Latin America, together make up slightly more than half of the estimated potential. Other studies have found that if agricultural land is dedicated to energy crops the former USSR and East Asia have considerable potential as producers of these energy crops [62].

The estimated technical potential of biomass can be compared with estimates of future demand in order to estimate the risk of global scarcity. The use of biomass in 2040 in the IEA’s 450ppm scenario is 106 EJ/yr [21]. This corresponds to 40-66% of the potential estimated in GEA, but more than 100% of what is considered sustainable in more conservative estimates. It is therefore likely that biomass resources will be subject to significant competition in renewable energy systems. However, the power density of biomass, calculated as energy per unit of time and area in the extraction region (e.g. W/m^2), is several orders of magnitude lower than that of fossil resources or fissile material in places where these exist [63]. Biomass also has lower power density than wind power and solar PV (see Table 2). Therefore, based on the physical properties of biomass, i.e. its spatial distribution and low power density, the geopolitical incentives and possibilities to secure, accumulate and control biomass resources over time and space are low in comparison with those for non-renewable resources. This implies that the risk of interstate resource conflicts, previously witnessed for fossil fuels, is low for biomass. This conclusion is supported by empirical studies of past resource conflicts [64].

Table 2. Approximate power density of current technology and global potential for renewable energy from different sources. Values for fossil oil are provided for reference.

	Biomass	**Wind power**	**Hydro power**	**Solar PV**	**Oil (fossil)**
Power density (W/m^2)[a]	0.1-1	1-15	0.1-100	10-20	10^3-10^4
Use in 2012 (EJ)[b]	56.3	1.9	13.2	0.35	176
Demand in IEA 450ppm scenario for 2040 (EJ)[b]	106	18	25	7	136
Global technical potential (EJ/year)[c]	160–270	1250–2250	50-60	62,000–280,000	N/A

[a] The literature provide a wide range of estimates [63, 65-67]. Values are generally in the lower part of the range, but geography and favourable environmental conditions increase the density in some locations, e.g. the power density of hydro power is sensitive to vertical drop and depth:width ratio of the reservoir, solar PV is sensitive to latitude since this affects light intensity.

[b] Data from IEA [21].

[c] Data from GEA [25].

On the other hand, the low power density of bio resources results in a large land requirement, which makes the resource difficult to control over time and space, and the entry barriers are low (i.e. it is easy to chop down tress in a forest). This makes theft of biomass feasible, which can provide revenue to belligerents exchanging the biomass for money. This is in line with previous findings; for example, Le Billon [68] reported that theft of timber has been used to fund rebels in a similar way as theft of oil. Increased demand for biomass makes biomass more valuable and its theft increasingly attractive for non-state actors.

The combination of large land requirements and increased competition raises issues of the environmental impact from the utilisation of renewable energy resources. The risk of environmental conflicts is different for renewable energy and fossil resources. The global impact, e.g. carbon dioxide emissions, is generally lower for renewables (although the difference between biofuels can be large depending on factors such as soil carbon, feedstock and energy used in the production process [69]). The local environmental impact can on the other hand be higher due to changes in land and water use [70] (see Table 3). This is especially noticeable for large-scale cultivation of bioenergy, which can contribute to displacement of indigenous people, i.e. land grabbing, and cause conflicts between states and local actors [71, 72]. The risk can be mitigated if implementation practices are socially inclusive and production technologies that provide synergies between local production of both biofuels and food are utilised (see e.g. Ref. [73, 74] for examples of such technologies). Wind and solar electricity are easier to integrate, since these technologies permit the same area of land to be used for multiple purposes such as on-shore wind farms located on pasture or arable land and rooftop solar PV.

Table 3. Examples of estimated life cycle greenhouse gas (GHG) emissions and water requirements (WRC) for renewable energy from different sources.

	Hydropower	**Wind power**	**Solar PV**	**Biomass**	**Bioethanol**	**Petrol**
GHG emissions (g CO_2 eq./kWh)	10	34	50	22-41	10-240	324
WRC (m^3/GJ)	4.7-58	0.001	0.004-0.01	2-64	10-76	0.36

Note: Values for GHG emissions for hydro, wind, solar and biomass are from Ref. [75] and for bioethanol from Ref. [76]. Values for WRC are adapted from Ref. [77, 78]. The literature provides a wide range of estimates that differ depending on technology/crop, geographical location, assumptions on land use changes and allocation rules used in the study. The WRC values only include water consumed during operation, i.e. not water withdrawal.

Concerning renewable electricity production, the global potential from wind and solar is vast compared with estimated demand and its power density is slightly higher than for biomass (see Table 2). Unlike biomass, there are higher entry barriers (e.g. investment costs) that discourage intruders from constructing renewable electricity production facilities on seized land, as electricity is produced as continuous flows that require investment in order to transport it over long distances or store it in energy carriers. This increases the upfront cost and, since large areas of land are needed, the risk of interstate conflicts for land to be used for renewable electricity production from solar and wind is low. A potential exception is areas that already have electricity production facilities in place, especially hydropower, which is likely to have a strategic value as a result of its capacity to store large amounts of energy at relatively low cost.

The risk of interstate water wars as a result of new hydropower dams is very low, since trans-boundary water resources typically result in interstate collaboration [79]. This is not to say that there can be no interstate water conflicts, only that these have historically been resolved peacefully much more often than through the use of force. Concerning intrastate water conflicts, previous research has found that the risk of conflict depends on institutions (e.g. democracy and political stability) and demand-side factors (e.g. economic development) rather than physical (absolute) water scarcity [80, 81]. Construction of new hydropower dams increases the risk of local conflicts if the local society experience relative water scarcity, since control of water storage transfers control of access to drinking water and irrigation away from local actors.

The risk of a "renewable electricity resource curse" is low compared with the risk of the "fossil resource curse", since the resource itself is not subject to depletion and fluctuations in revenues are lower [14]. Moreover, the higher upstream investment costs, low power density and wide geographical availability of renewable resources mean that countries that export renewable electricity are not able to earn as high revenues as current exporters of fossil energy. Social tensions can be reduced if there are transparent processes and fiscal rules that enable social inclusion in the scaling-up, construction and operation of new renewable production plants [14, 82, 83]. This is an issue of good governance that importers can influence by demanding that exporters develop adequate institutional capacity and assist them in this. However, even if they fail to do so or do not attempt to, the risk of domestic instability that can cause, or prolong the duration of, a conflict is still lower than for fossil resources as excess profits are lower. Furthermore, the high entry barriers for renewable electricity production and export prevent belligerents from utilising these resources to fund their activities.

3.2 International trade

The global gross energy content of all harvested biomass (food, feed, fibre, energy, etc.) is approximately 230 EJ, of which 7.5 % is traded internationally [84]. Approximately one-fifth of the harvested biomass (50 EJ) is used for energy purposes, but only a few percent of this (0.9 EJ) is traded internationally [85]. The international net trade in biofuels amounted to approximately 0.13 EJ in 2009 [86].

The international trade in bioenergy can develop in different directions depending on e.g. the implementation of climate change mitigation policies, availability of biomass and economic growth. Hansson et al. [62] estimated the maximum potential of international trade of all biomass for energy purposes in 2050 to be within the range 80-150 EJ/year. In a scenario analysis, Jewell et al. [8] concluded that by 2050 the likely interregional trade in biofuels, i.e. a subgroup of the trade in biomass, will be 15 EJ/year and that regional self-sufficiency in energy will increase. Assuming that the global biofuel trade increases as proposed in that study it is likely that international trade and number of exporters will increase, since the potential for bioenergy is geographically distributed. Trade in biofuels is currently not subject to as sophisticated market schemes as oil (e.g. a derivatives market that increases liquidity and reduces the need for low-transparency, over-the-counter arrangements), but there is reason to believe that corresponding market schemes would develop in co-evolution with increased use of biofuels, since such services reduce transactional costs.

Compared to fossil energy, renewable electricity trade increases interdependence and reduce the economic incentive to use the energy weapon [13, 87]. The main explanation is that renewables utilise flows instead of stocks and that this makes it expensive to control and accumulate resources over time. A decrease in flow results in foregone earnings, since there is a high discrepancy between variable production costs and the market price. For fossil resources, it is easier to shift the delivery to a later point in time, since ’production‘ entails extracting a finite stock. Fossil resources are also easier to store. Essentially, since the producer of renewable electricity would suffer (economic) harm from restricting the flow, the producer’s political leverage is low and the interdependence between exporter and importer can be high. Therefore, international electricity trade is more likely to incentivise bilateral- or multilateral cooperation that enables positive security rather than conflicts. For example, Xin-gang et al. [88] concluded that China and its neighbours can achieve mutual benefits from transnational electric interconnections and similar collaborations. In a historical example, the forerunner of the European Union, the European Coal and Steel Community (ECSC), facilitated trade and collaboration among Western European countries that were previously enemies.

3.3 Conversion and distribution

Energy systems that are exposed to intentional attacks and vulnerable can be attractive targets for malicious events intended to cause disruptions, performed by state or non-state actors. Three issues needs to be addressed, 1) if the system has components of high energy density that are exposed to an attack, 2) if the system is sensitive to component failures (e.g. cascading events), and 3) if what the system symbolise make it more attractive as a target.

The generally low power density of renewable energy resources and production (see Table 2) indicates that the upstream sector can be more exposed than for fossil resources, but the incentive for a physical attack on production facilities is low since a substantial amount of these facilities would need to be affected to cause major disruption of energy production. System parts with high energy density are more likely to be critical for the functionality of the system and if a handful of these are disabled the consequences can be proportionally large. The energy density of the renewable energy distribution system can be similar as fossil energy systems. For example, parts such as infrastructural bottlenecks, energy carriers or storage have high energy density (see Table 4). Thus, the risk of terrorists physically attacking renewable energy systems is similar to that for non-renewable energy systems, as previously reported [89]. These attacks are rare in domestically stable countries because of the complexity of arranging a coordinated attack on several bottlenecks and collateral damage that can result in a backlash and reduce support for the terrorists [45].

Table 4. Indicative values of energy density for renewable energy resources, carriers and storage, with values for petrol provided as reference.

	Biomass/ Dry wood[a]	**Ethanol**	**Electricity storage[b]**	**Hydrogen (liquid)**	**Petrol**
Energy density (MJ/kg)	>20	30	13	142	47
Energy density (MJ/litre)	>5	24	12	10	36

[a] Values can differ depending on e.g. moisture content; source [91].

[b] Theoretical value provided for battery storage using non-aqueous Li-O_2; source [92].

Besides feasibility and consequences, the symbolism of attacking a target can contribute to its selection by terrorists [45]. Decentralised renewable energy systems can be associated with, and represent, a different image to the ‘hard path’ political economy of centralised fossil systems [90]. A symbol of social inclusion is less prone to increase conflicts and be attacked than a symbol of centralised political power.

Energy systems can also be targets of enemy states, in which case collateral damage can be seen as a benefit rather than obstacle for the attacker. An example is the British operation Chastise during WWII, when the Möhne and Edersee dams in Germany were bombed and parts of the Ruhr valley were flooded. The risk of such physical attacks is obviously low unless there is an ongoing interstate war.

Dependence on industrial control systems, which are a central part of the smart grid, exposes this critical infrastructure to cyber-attacks [93]. Foreign states can conduct cyber-attacks, even if they are not at war, since it is difficult to trace the attacker, providing “plausible deniability” [94]. However, the control system is a difficult target and a successful cyber-attack would thus require a skilled attacker [95]. It is therefore mainly insiders and states that have the required capability to attack the control system. Large-scale electricity systems, particularly the transmission grid, are also sensitive to attacks that disable a small amount of critical parts. Albert et al. [96] simulated the North American grid and found that it was sufficient to remove 2% of transmission nodes to cause 60% loss of connectivity. A system that is attacked in this way starts to fragment, i.e. parts of the distribution system becomes disconnected from the transmission grid. Therefore, small-scale renewable electricity reduces the sensitivity to these attacks, since it is typically connected to the distribution grid and located close to users. Large-scale renewable production connected directly to the transmission grid does not, e.g. large-scale hydro and offshore wind farms.

3.4 End use

The strategic value of energy carriers can be high if end-use sectors that are critical for a society have low flexibility to substitute certain energy carriers or reduce demand. Such characteristics incentivise states to use force to secure flows. Dependence on secure flows also makes societies vulnerable to disturbances and attacks on flows.

Some development trajectories for end use interact with how renewable energy is integrated within energy systems, for example electric vehicles that use batteries enable a high penetration rate of variable electricity production. Technologies, and behaviour, that increase flexibility and capacity to respond to disruptions (e.g. ability to shift between fuels or modes of transport) reduce the perceived strategic value of certain energy carriers.

A scenario study of future energy systems concluded that the diversity of the transport sector, measured as balance and variety of primary energy sources, is currently low (0.2). In a baseline scenario it would be higher (0.7) in 2050, but diversity is even higher in decarbonised scenarios (1.3-2.0) [8].[4] If this development is combined with fuel flexibility, as in hybrid or flexi fuel-cars, the ability to substitute energy carriers and respond to disruptions increases [97]. Electrification of the road transport sector that utilise battery storage or plug in hybrids appears a favourable option from this perspective, since it increase demand-side flexibility and electricity can be produced from various renewable sources that are not subject to risks that correlate with the risks of liquid fuels. Enhanced sustainability of spatial planning, such as an urban form that enables modal shifts and individuals avoiding journeys, further increases the flexibility to respond to disturbances and cope with stress [98].

Concerning the cost and affordability of renewable energy systems, some authors claim that the total system cost is not necessarily affected in the longer term, or may even decrease,

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[4] Diversity was measured as dual diversity (i.e. balance and variety of a portfolio) using the Shannon-Wiener diversity index.

but there is a shift in the cost structure as variable costs occurring over time are reduced at the same time as fixed costs, i.e. upfront investments, increase [99]. If most of the energy is produced domestically it is thus possible for a state to have a stable cost of energy and reduce the transfer of wealth to other states during a price spike. However, other authors claim that maintaining current levels of reliability in industrialised countries would be too expensive in renewable energy systems, at least during the transition, and as a consequence it would be more economically efficient to aim for a lower level of reliability [100]. If so, the lower level of reliability would most likely materialise as higher price volatility. Even if this were the case, it is uncertain whether societal stability would be affected, since studies connecting declining affordability and social unrest have analysed a principally different contextual situation, i.e. involuntarily reduced livelihood in developing countries rather than a normative transition of mature economies.

To summarise, renewable energy *per se* does not increase end use flexibility but its implementation provides a possibility to increase it. Particularly if ancillary policies that promote a sustainable low-carbon transition of the transport sector are implemented, e.g. reduced demand, enabling modal shifts (e.g. commuting by train or bicycle instead of car) and reduced vulnerability to price fluctuations (e.g. improved energy intensity or behavioural change).

4. Discussion

The risk of renewable energy being a conflict objective, i.e. with actors competing over scare resources or control of these, is considerably reduced for renewable energy systems compared with fossil energy systems. The main explanation is that renewable energy resources are more evenly distributed and production covers larger areas, as energy densities are lower. In general, this makes it difficult to secure and exert control over resources and results in a low strategic value of renewable resources. As a consequence, if the energy system is mainly based on renewable resources it becomes less rational, not only from an economic but also geopolitical point of view, to use force to improve control over, or access to, energy resources. The incentive for these types of conflicts also depends on how end-use and flexibility develop. A (more) sustainable energy system can have higher end-use flexibility, but this development is only partly related to utilising a larger share of renewables. The development of other areas, particularly the road transport sector, influences the flexibility, which can be higher or lower in renewable systems, as pointed out in section 3.4.

There are some differences between how bioenergy systems and renewable electricity from wind, hydro or solar PV interact with conflicts. Bioenergy is more likely to cause local conflicts related to scarcity of natural resources (e.g. competition of land use and water) and the resource curse, since it can be used as a source of revenue to fuel intrastate conflicts. Renewable electricity systems, especially large-scale systems, can be vulnerable, exposed to hostile attacks and thereby used as a means in a conflict in a similar way as fossil-based systems (see Table 5).

Table 5. Summary of interactions between renewable energy systems and conflicts.

Stage in the supply chain	**Bioenergy, biofuels**	**Renewable electricity (wind, hydro, solar PV)**
Primary resources	More likely to interact with local conflicts (social instability) than interstate conflicts, because resources have low power density and are geographically widespread, but large land	Low risks of interstate and intrastate conflict, since resources are abundant and geographically widespread and there are entry barriers to production that restrict opportunities for belligerents. An

	requirement and low entry barriers for production.	exception is hydropower which can increase tension between local actors and states that have insufficient institutional capacity.
International trade	Low risk of conflict, since the number of exporters is assumed to be high in a decarbonised future.	More likely to incentivise interstate collaboration than conflicts, since mutual benefits can be achieved from increased (regional) trade and interdependence.
Conversion and distribution	Similar risk as current systems for liquid fossil fuels, since the system has similar structure (e.g. energy density of bottlenecks).	Small-scale systems have a very low risk of being attacked (i.e. used as a conflict means). Large-scale systems that utilise control systems are exposed to virtual attacks from hostile states. The risk of physical attacks is similar as for fossil systems.
End use	The interaction is uncertain and depends on which energy end-use technologies are implemented (e.g. effects on flexibility of demand). Ancillary sustainability policies (e.g. increased energy intensity, fuel and modal shift) reduce the risk.	The interaction is uncertain and depends on which energy end-use technologies are implemented (e.g. effects on flexibility of demand). Ancillary sustainability policies (e.g. increased energy intensity, fuel and modal shift) reduce the risk.

Some factors that can affect the risk of conflict during transition remain uncertain and/or can evolve in different directions, such as the design of technical infrastructure (e.g. is the system sensitive to an attack?), how the system co-evolves with international institutions (e.g. how will foreign relations develop?), what the system symbolises and how it is implemented (e.g. is it including or excluding actors?) and how fossil incumbents perceive the transition and (re)act.

Incentives for physical attacks on renewable energy systems and for using them as means in a conflict can be even lower than for fossil based energy systems, but the extent of the risk reduction depends on the scale of production facilities and distribution, as well as interdependences within the renewable system that make them sensitive, e.g. as a result of system topology. The use of smart grid and related industrial control systems increases exposure to virtual attacks by skilled (foreign) enemies. The energy weapon, i.e. one actor using energy flows to gain political leverage, is less likely to be used in renewable energy systems.

Fossil ‘resource wars’ take place at the international arena and are geopolitically motivated. States are the main actors competing for scarce resources and using military force to project their power. This level of analysis is inadequate to study renewable energy conflicts, as it masks the conflicts that have a high risk. For example, ecological conflicts, caused by the use of land and renewable resources for energy purposes, involve both state and non-state actors and are smaller and geographically closer to the local energy system. It is possible to prevent such conflicts if the transition to renewables is part of an inclusive sustainable development and the livelihood of local actors is not threatened. Because of these changes, concerning incentive, actor and scale, it may be useful to study renewable energy conflicts from a bottom-up perspective, such as to use the human security paradigm, rather than from a state-centric perspective.

A limitation of this study was the approach to the renewable energy system as a new system rather than a pathway and transformation of the current system. The transition away from the fossil fuel era will both open up new opportunities for peaceful futures and close down other peaceful pathways [101]. These changes challenge the path dependency of existing energy systems and the prevailing political economic paradigm and actors benefitting from it [102, 103]. For example, incumbents with vested interests in current systems, such as hegemonic actors and producers of fossil fuels, may perceive it as a threat, since they lose power and influence that is intrinsically linked with a centralised fossil energy system. It is therefore possible that some will seek to prevent such a development trajectory. To what extent this can result in conflicts was outside the scope of this study and is an area for further investigation by social science scholars.

5. Conclusions

The 20th century witnessed both the rise of the fossil fuel era and interstate conflicts motivated by competition for access and control of these resources. If the 21th century turns out to be the ’century for renewables‘ this study suggests that we can anticipate a different set of energy conflicts. The risk of violent interstate conflict will be lower, but large-scale utilisation of renewable energy resources would increase the risk of local instability in societies that have insufficient institutional capacity and where actor’s livelihood is negatively affected.

The geopolitical and economic incentive for states to engage in interstate conflicts for access and control of renewable energy is low, since renewable resources have a relatively low strategic value because of their physical properties (i.e. geographical distribution, low power density, energy flows rather than stocks that are difficult to accumulate and control over space and time). Systems that are diversified and/or flexible (e.g. can switch between different resources and energy carriers) further reduce the incentive to secure certain resources.

A transition to renewable resources does not in itself alter the fact that energy is a basic good, that energy systems can be vulnerable and that systems can be a target for hostile attack. The incentive to attack a renewable energy system depends more on how these systems are designed and how the demand side develops than on whether the resource is renewable or not. Renewable energy systems can be designed to have a low risk of being attacked. For example, decentralised renewable systems with a high level of resilience have a very low risk of being attacked because the effects of an attack would be low.

Renewable energy can cause local conflicts that involve non-state actors, such as ecological conflicts. This is mainly the flipside of high land area requirement, low entry barriers to harvesting biomass that enable illegal logging and potential interactions with agricultural systems for food production. Preventing such conflicts requires development of local institutional capacities. The involvement of non-state actors in conflicts at sub-national scale illustrates that it can be beneficial to approach renewable energy conflicts from a broader and deeper perspective on security than conflicts related to fossil resources.

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