The impossible energy trinity: Energy security, sustainability, and sovereignty in cross-border electricity systems

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ABSTRACT

The article explores energy policy tradeoffs faced by states that expand renewable electricity production and are part of cross-border electricity systems. We develop the concept of an impossible energy trinity (IET), which posits that many states cannot simultaneously achieve energy security, sustainability, and sovereignty. We argue that these states have three options to cope with the challenge of intermittent electricity production from domestic renewables. The dirty option resorts to base or reserve electric generating capacity from non-sustainable sources. The insecure option accepts system stability risks and/or higher electricity prices. The non-autonomous option cedes control over domestic energy rules to pursue integration with neighboring electricity grids and markets. We empirically illustrate our novel concept using the case of Switzerland, which finds itself at the crossroads of the three options. The country has to choose whether to add conventional generation capacities, accept grid instabilities and higher electricity prices, or integrate with the EU electricity market and rules. We discuss generalizations to other countries and ways to manage the IET. We conclude that public pressure for decarbonization and economic pressure to maintain secure energy supply render the non-autonomous option most likely in many states. The operation and governance of transboundary grid structure thereby influence energy transitions on national and subnational scales.

1. Introduction

Although global renewable electricity production is on the rise (IEA, 2021, pp. 26–28), countries differ in their ability to pursue a domestic energy transition. Multidisciplinary scholarship has identified technical, economic, and political challenges. These include the volatility of energy production from renewable energy sources (RES; Sinn, 2017), investment barriers for RES (Hu et al., 2018), and issues of social acceptance (Wüstenhagen et al., 2007). Few countries, such as the United States, may be able to cope rather easily with these challenges. Their natural endowments, energy system infrastructure, and market size facilitate the diversification of RES and provide flexibility and storage options (Scholten & Bosman, 2016, pp. 277–280). By contrast, many other countries are less well-endowed in these respects. They can compensate these structural disadvantages by integrating their electricity systems and markets with neighboring countries. Such cross-border electricity systems support *energy security* through access to flexible balancing power and the leveling of energy demand and supply across larger areas (Bahar & Sauvage, 2013, pp. 13–14). Integrated electricity markets also promote *sustainable energy* as larger markets that allow for exploiting competitive advantages and economies of scale attract green investments (Buschle, 2014, p. 17; Hu et al., 2018). Yet,

system and market integration presuppose common rules as well as supranational oversight and enforcement mechanisms that may curtail *energy sovereignty*.

Based on this constellation, we ask what tradeoffs states face in the energy transition. We argue that, because of their limited endowments and dependence on other countries, many states are subject to an ‘impossible energy trinity’ (IET): energy security, sustainable energy, and energy sovereignty cannot be maximized simultaneously. Instead, these states have to prioritize two of these objectives, leaving them with three policy choices: a ‘dirty option’ sacrificing sustainability, an ‘insecure option’ compromising energy security, and a ‘non-autonomous option’ relinquishing energy sovereignty. We investigate this argument using evidence from Switzerland. Although the Swiss government officially pursues all three objectives (Federal Council, 2021a), we observe manifestations of tradeoffs as expected in the IET. Having moved from a dirty into an insecure option in the past, the country faces a tough choice today: Electricity cooperation with the neighboring European Union (EU) would increase Swiss energy security at the expense of sovereignty, whereas the preservation of sovereignty would weaken the sustainability and/or security of electricity supplies. We discuss that these findings are exemplary for the constraints that many countries face in the energy transition.

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Our main contribution to energy studies is the argument that, for many states, a transition to a RES-based energy system is likely to impose sovereignty costs and increase the level of energy policy integration with their neighbors. Scholars in domestic energy politics have analyzed the impact of domestic interests, ideas, and institutions on energy policy choices (Jacobsson & Lauber, 2006; Rinscheid, 2015). Current societal pressures for an expansion of renewables and continued secure energy supply push countries to exploit advantages of cross-border electricity systems. Yet, integration leads to reduced autonomy in energy policymaking. International relations scholarship explains how global interdependencies affect countries' energy security (Casier, 2011; Chester, 2010) and analyzes new interdependencies resulting from the clean energy transition (Meckling & Hughes, 2018). Research on EU external energy governance highlights structural interdependencies between the Union and its neighbors and discusses resulting power relations (Godzimirski, 2019; Hofmann et al., 2019; Lavenex & Schimmelfennig, 2009).

Our argument links political science and international relations scholarship to the field of energy geography. Energy geography has advanced geographical, geopolitical, and geoeconomic perspectives on socio-technical energy transitions and begun to link these to spatial characteristics of low carbon energy systems (Bridge et al., 2013; Calvert, 2016). Recent research in the field notes the significance of scale in shaping energy systems and politics (Chateau et al., 2021). However, there is a need to better understand "the transboundary challenges within energy systems as well as the scalar challenges/politics of governing energy systems" (Baka & Vaishnav, 2020, p. 9). We contribute to such an understanding by exploring domestic and foreign policy trade-offs that countries face in the energy transition. One implication of our study is that transition processes at national and subnational scales are linked to transboundary challenges in electricity grid operation and governance.

Subsequently, we theorize energy transition tradeoffs by introducing the novel concept of an 'impossible energy trinity'. We then empirically assess this IET in the recent energy policy of Switzerland. Next, we discuss to what extent our framework might be applicable to other states. We conclude that the IET puts pressure on the energy sovereignty of many states that are transitioning to renewables.

2. Conceptualizing the impossible energy trinity

In this part, we develop our conceptual argument about the existence of an IET in three steps. First, we define the three energy policy objectives of security, sustainability, and sovereignty. Second, we explain how the energy transition creates an IET with a tradeoff between energy policy objectives. Third, we reflect on possibilities and choices to manage this tradeoff.

2.1. Three energy policy objectives: security, sustainability, and sovereignty

We posit that the basic orientation of a country's energy policy can be usefully captured by the objectives of energy security, sustainability, and sovereignty. Our focus on these objectives is driven by analytical interest rather than normative judgments about which objectives should be valued. All three terms have figured prominently in energy research and are subject to competing conceptualizations. Below, we define these objectives and reiterate why they are central to energy policy.

The notion of energy security has become ubiquitous in discussions about energy governance and climate change. Policy documents, reports, and academic research have associated the term with uninterrupted access to sources of energy, diversification of sources and routes of supply, abundant supplies, resilience against external shocks, and energy self-sufficiency. Despite its discursive pervasiveness, energy security remains an elusive concept (Ang et al., 2015; Chester, 2010). In this article, we operationalize energy security based on three

dimensions: availability, accessibility, and affordability (APERC, 2007; Kruyt et al., 2009). Unlike most definitions that implicitly refer to energy security in a fossil-fuel world, this approach accommodates contextual novelties of the post-carbon era like the unparalleled use of RES and increasing electrification of energy systems. We refer to *accessibility* as direct access to sufficient primary energy sources to meet demand. RES like wind, solar, and hydropower are more equally distributed across the globe than fossil fuel resources. Access is not a sufficient condition for energy security though as it does not guarantee availability. *Availability* denotes uninterrupted energy from domestic and external sources. This dimension gains in relevance as the share of electricity from intermittent RES in the energy mix is growing. In contrast to other energy carriers, electricity cannot be stored cheaply and easily at present. Depending on domestic access to RES and the conditions under which they can be harnessed, the provision of uninterrupted electricity can be costly. *Affordability* stresses the supply of energy at competitive price levels. These three dimensions reflect the core of the IEA's energy security definition: "ensuring the uninterrupted availability of energy sources at an affordable price" (IEA, 2020). Some consider acceptability as a fourth dimension of energy security (APERC, 2007; Kruyt et al., 2009). We do not include acceptability though as it lacks specificity (Cherp & Jewell, 2014, p. 417) and focuses on environmental concerns (APERC, 2007, p. 27 ff.), which we cover under the separate objective of sustainability.

Sustainable energy denotes the pursuit of a carbon-neutral energy system based on RES. RES "are continually replenished by nature and derived directly from the sun (such as thermal, photo-chemical, and photo-electric), indirectly from the sun (such as wind, hydropower, and photosynthetic energy stored in biomass), or from other natural movements and mechanisms of the environment (such as geothermal and tidal energy)" (Ellabban et al., 2014, p. 749). This definition excludes fossil fuels like oil, gas, and coal, as well as nuclear power. While the exclusion of fossil fuels is uncontroversial, countries like France or Finland rely on nuclear power to decarbonize their economies (Teräsväinö et al., 2011). We agree that nuclear power is a low-carbon technology but maintain that it is not fully sustainable. The main reasons are that uranium deposits are non-renewable and that many questions on nuclear waste disposal remain unresolved. Furthermore, while some authors consider nuclear and renewable energy to be compatible (Cany et al., 2016), recent findings indicate that the two tend to crowd each other out (Sovacool et al., 2020). From a consumption perspective, a truly sustainable energy system requires a phase-out of non-renewable sources from both domestic production and the electricity import mix.

Sovereignty is "the power of a country to control its own government" (Cambridge Dictionary, 2020). Political theorists contrast internal sovereignty, i.e., ultimate authority within a territory, with external sovereignty, i.e., recognition of that authority by others (Biersteker & Weber, 1996, p. 2). Internally, energy sovereignty refers to the empowerment of communities to decide about energy systems (Schelly et al., 2020, p. 110). Externally, energy sovereignty comprises protection from supply disruptions by outside actors (Cherp et al., 2012) and protectionist policies against regulatory competition (Crossley, 2013). Since we deal with international energy relations, we emphasize the external dimension but move the focus from energy supplies to policy-making. We define energy sovereignty as a country's ability to decide independently about the structure and sources of its energy supply (the 'hardware' of energy governance) and about its energy policy, including energy market and system operation rules (the 'software'). Hence, sovereignty here denotes the ability to make decisions about energy free from foreign influence and interference rather than self-sufficient energy supply. To the extent that a country's energy policy features rules set or influenced by other states, the energy sovereignty of that country is reduced. This definition is grounded in empirical observations that domestic concerns over policy control continue to greatly influence regional energy integration (Bocquillon et al., 2020). Table 1 summarizes our definitions of energy security, sustainability, and sovereignty.

Table 1
Definitional elements of core concepts.

Concept	Main definitional elements
Energy security	<ul style="list-style-type: none"> • Accessibility: access to sufficient energy sources • Availability: uninterrupted provision of energy supplies • Affordability: energy at competitive price levels
Sustainable energy	<ul style="list-style-type: none"> • Carbon-neutral electricity generation and consumption mixes • Exclusion of nuclear energy
Energy sovereignty	<ul style="list-style-type: none"> • Ability to take independent decisions about structure and sources of energy supply ('hardware') • Full control over energy policy, market rules, and operation of the energy system ('software') • No interference from outside

Source: authors.

2.2. The impossible energy trinity

We argue that the transition to a renewable-based energy system involves an IET for many states in the form of tradeoffs between the three objectives of energy security, sustainability, and sovereignty. Because electricity generation from RES is more volatile than from fossil fuels, energy systems need to be adapted to ensure uninterrupted availability of electricity (Sinn, 2017). To compensate for temporary low production from one renewable source (e.g., wind not blowing or sun not shining), countries need diversified RES portfolios as well as storage and balancing options (Papaefthymiou & Dragoon, 2016). Regarding domestic RES portfolios, many states can deploy only certain RES efficiently. Accordingly, they depend on cross-border markets to import electricity from RES that they cannot harness cost-efficiently or that are temporarily unavailable due to intermittency (Bahar & Sauvage, 2013). Disconnected or closed markets do not only limit such imports but also create risk-related constraints on investments in diversified RES. Notably, infrastructure developments hinge on business opportunities for selling domestic excess production from RES (Buschle, 2014, p. 17; Hettich et al., 2020, p. 101; Hu et al., 2018). These opportunities diminish when a country lacks a large electricity market or access to it. Moreover, underdeveloped electricity trade with neighboring countries impedes efficient balancing of demand and supply differences and increases the need for more costly domestic flexibility measures (Scholten & Bosman, 2016, p. 280).

States integrated into cross-border electricity markets may find it easier to satisfy the flexibility needs of a renewable-based energy system in cost-efficient ways. Extended electricity grid size provides, *ceteris paribus*, a more varied energy geography that eases diversification of RES and electricity storage. Additionally, market coupling reduces commercial risks for professional investors in renewable energy development by enabling economies of scale and broadening marketing options (Newbery et al., 2016). Integrated electricity networks also facilitate system resilience at lower costs by enabling cross-border adequacy coordination and balancing markets that reduce the need for domestic flexibility options. Overall, electricity system integration with neighbors improves a country's position regarding diversified RES, attractiveness of infrastructure investments, and system balancing. This helps manage the domestic energy transition whilst ensuring sustainable and secure energy.

For many states, however, cross-border electricity integration creates an IET (Fig. 1). Electricity system and market integration requires common rules as well as joint monitoring and enforcement mechanisms. Such needs may also arise from other cross-border infrastructures (e.g., gas networks) but the technical complexities of operating cross-border electricity grids stand out. Physical, regulatory, and political interdependencies force states to cede sovereignty by transferring authority over domestic electricity rules to foreign or supranational institutions (Buschle, 2014, p. 18; Hofmann et al., 2019). Conversely, preservation of full authority would undermine integration and thereby compromise energy security and/or sustainability. It follows that, in

Fig. 1. The impossible energy trinity

Source: authors.

pursuit of an energy transition, states cannot simultaneously achieve the three objectives of energy security, sustainability, and sovereignty. Drawing on a metaphor from international political economy (Boughton, 2003), we call this the impossible energy trinity. The following subsections outline policy options to manage the trinity and the main factors influencing these choices.

2.3. Three policy options to manage the IET

Our IET is 'impossible' in the sense that many countries cannot resolve but only manage it. While policymakers may seek simultaneous progress in energy security, sustainability, and sovereignty, we argue that they will always need to prioritize two of these objectives. Similar thinking is underlying the so-called "energy trilemma" in socio-environmental studies, which highlights the incompatibility of simultaneously achieving energy security, energy equity, and environmental sustainability (Gunningham, 2013, p. 185). The impossible energy trinity we propose is conceptually different. It addresses geopolitical aspects of energy transitions by considering energy sovereignty instead of equity and by stressing tradeoffs in cross-border electricity systems. Nevertheless, the idea that tradeoffs can only be managed through dedicated policy choices applies to both concepts. In our IET, this leaves decision-makers with three ideal-typical policy options:

- The 'dirty option' maintains energy security and sovereignty by relaxing sustainability objectives. Pursuing energy sovereignty implies that a country avoids integration into cross-border electricity systems since this requires shared rules for operation, trade, enforcement, and litigation. Rejecting external interference imposes limitations on participation in cross-border adequacy coordination and electricity trade. Energy security then needs to be ensured through domestic generation. However, many countries lack fully diversified RES or sufficient natural storage options for accessible, available, and affordable electricity. To maintain energy security, they would have to fall back on cheap and reliable conventional energy carriers. Such electricity generation from fossil fuel or nuclear sources is incompatible with our definition of sustainable energy. Therefore, the prioritization of energy sovereignty and security is a 'dirty option'.
- The 'insecure option' maximizes sustainability and energy sovereignty at the expense of energy security. Preserving full energy sovereignty, a country could autonomously transform its domestic energy system to RES. Yet, without cross-border cooperation, this process entails inefficiencies regarding accessibility, availability and/or affordability of energy. In the absence of efficient trade

mechanisms and adequacy coordination with neighbors, system stability fully depends on domestic sources. This excludes conventional generation capacity when sustainable energy is pursued as a second objective. Ensuring uninterrupted supplies then requires a full diversification of domestic renewable generation capacity and storage. Since comparative advantages in these technologies are typically limited and private investors may perceive smaller, closed markets as risky, public subsidies can incentivize the necessary investments. The funding of public subsidies from energy-related taxes or levies increases domestic electricity prices and reduces the affordability of energy. As an alternative to subsidized domestic diversification, energy availability could be compromised, but this is an unlikely choice in modern, energy-dependent economies. Either way, the pursuit of energy sovereignty and sustainability impairs energy security objectives.

- c) The 'non-autonomous option' pursues secure and sustainable energy but sacrifices sovereignty. A country could integrate its electricity system with those of neighboring countries to facilitate an efficient domestic energy transition. Market integration and cross-border trade would allow for exploiting comparative advantages in electricity generation and storage and for balancing intermittent supplies. Such available and accessible electricity at affordable prices facilitates energy security. Efficient cross-border markets for renewable electricity also promote sustainable energy by reducing the need for backup generation capacity from dirty sources. Yet, this would require regulatory harmonization, which reduces the ability to make policy choices free from foreign influence or interference. Energy policy is then bound by policy decisions taken abroad or at higher governance levels, even if some customization in domestic implementation might be possible (Hofmann et al., 2019). Hence, many states pursuing energy security and sustainability through cross-border cooperation must accept energy sovereignty losses.

We depict these policy options as zones in which different specific combinations are possible. Still, the IET forces states to accept suboptimal outcomes on at least one objective.

2.4. Factors shaping the choice of policy options

Previous research has identified different variables shaping energy policy choices. We do not aim to explain systematically all policy choices within the IET. Rather, we restrict ourselves to highlighting the most important political and geographic factors that are likely to interact with the trinity.

For politics, three sets of variables deserve mention. First, many scholars argue that domestic interest coalitions influence energy policy choices. These choices depend on the strategies and relative power of the energy sector, energy-dependent industries, and advocacy coalitions (Cheon & Urpelainen, 2013; Jacobsson & Lauber, 2006) as well as on public opinion mediated through party politics (Anderson et al., 2017; Brouard & Guinaudeau, 2015). Second, research has shown that new ideas may be a prerequisite for energy policy change and can empower new coalitions (Cox & Béland, 2013, pp. 322–323; Rinscheid, 2015). The adoption of new ideas may reflect new knowledge or changed values and perceptions, for instance, about the benefits and risks of certain energy sources (Bird et al., 2014; Siegrist et al., 2014). Third, institutions can create path dependencies in the choice of energy policy goals. Techno-institutional complexes explain the long-lasting carbon lock-in of many countries (Unruh, 2000). By contrast, international commitments like the Paris Agreement can help to increase the level of domestic policy ambition (Röser et al., 2020), making the choice of a 'dirty' option unlikely. Moreover, even institutional decisions initially unrelated to energy may matter. For instance, EU membership comes with the requirement to implement the *energy acquis* (the EU's accumulated legislation, legal acts, and court decisions in the energy field) under guidance and monitoring of the European Commission

(Bocquillon & Maltby, 2020).

Beyond politics, the relationships between energy, space, and society studied by geographers (Bridge, 2018; Calvert, 2016; Huber, 2015) influence policy choices within the IET. This includes spatial patterns of resource development, power plant siting, energy distribution, transport, and consumption (Solomon et al., 2004). Decarbonization efforts challenge deeply-embedded practices of energy use (cf. Shove & Walker, 2014) and require new spatial imaginations (Huber, 2015). One aspect is in how far a country's absolute geographic characteristics, including its location and resource endowment, allow for a cost-efficient deployment of diverse RES and energy trade. Another aspect is how existing socio-technical constellations and activities of energy use ('energy landscape') shape the domestic energy transition (Bridge et al., 2013, pp. 334–336). These aspects include the adequacy of built infrastructure. For instance, the size and resilience of a country's energy grid determine its ability to balance supply and demand fluctuations efficiently across regions and via access to storage options (cf. Sinn, 2017). They also include the role of institutions and users of energy systems in the transition (Calvert, 2016). For example, the scale and shape of an electricity market influence a country's capacity to attract investments in renewable energy infrastructure (Buschle, 2014, p. 17; Hettich et al., 2020, p. 101). Yet, public concerns over changes to the energy landscape cause opposition to such renewable energy projects (Fast, 2013). Contested material and socio-technical spatialities in the energy transition (Bridge, 2018) thus reinforce constraints within the IET.

Geographic factors also have repercussions for the distribution of political power. The 'territoriality' of energy infrastructure (i.e., the spatial embeddedness of production sites, transmission, and distribution networks) represents geographical integration or partition (Bridge et al., 2013, pp. 336–337). Access to energy resources, including systems and sites of extraction, shapes conflict and cooperation between states (Huber, 2015). A typical example is the geopolitical power fossil fuel exporters exercise over energy-dependent states (Casier, 2011). Research on the 'geopolitics of renewables' highlights how the shift towards low-carbon energy sources creates new centers of geopolitical power (Paltsev, 2016; Scholten & Bosman, 2016). Cross-border electricity networks interconnect countries in unprecedented ways and provide new avenues of exerting geopolitical pressure (Westphal et al., 2021). However, energy-related dependencies are rarely one-sided. Energy exporters such as Russia, Norway, and Paraguay rely on other countries for market access and infrastructure investments (Folch, 2019; Szulecki et al., 2016, p. 559). In transnational energy regimes, like the pan-European energy market or the ASEAN power grid, shared infrastructure and regulatory harmonization limit autonomous domestic energy policymaking (Hofmann et al., 2019; IEA, 2019). International relations scholars note that in such constellations of interdependence, *asymmetries* are a source of influence (Keohane & Nye, 1989). The strongest limitations to influence and autonomy are experienced by countries with structural disadvantages, for example, due to their smallness (Panke, 2010).

Countries differ in how far these political and geographic factors constrain domestic policy choices. Those with undiversified RES and a small electricity market may be particularly dependent on their neighbors. However, only very few states have political, socio-technical, and natural preconditions allowing them to escape interdependencies. Countries of continental scale, like Australia or the United States, may possess sufficient diversified RES, a resilient electricity grid, a large energy market, and access to the sea. Moreover, technological developments such as the cost reduction for diversification of RES or electricity storage may reduce dependencies on neighbors. Yet, these changes are only gradual and will remain an issue throughout the transition phase. Many countries transitioning to an electricity system based on RES will face constraints in domestic energy policy choices in line with the IET.

3. Case study method

We use the electricity relations between Switzerland and neighboring EU countries to illustrate the IET. This is a revelatory case (cf. Yin, 2009, pp. 48–49) as it can make visible yet underexplored tradeoffs in the energy transition. Lacking EU membership, Switzerland's energy policy integration has proceeded less gradually than in EU countries and linkages to non-energy issues are less complex and more transparent. Therefore, the Swiss case offers good conditions for observing and linking potential losses of sovereignty to the pursuit of sustainable and secure energy. Another reason for the theoretical value of the Swiss case is that while important scope conditions of our argument are present, the presence of the IET appears a priori unlikely. The country is strongly attached to all three energy policy objectives among which we expect to find tradeoffs. First, Switzerland is unlikely to jeopardize energy security that is legally enshrined as sufficient, diversified, and economical supplies in the Federal Constitution (art. 89) and Energy Law (art. 1) and taken for granted by its population and economy (van Vliet, 2019, p. 145). Second, Switzerland is not prone to rapidly fall back on electricity generation from fossil fuels considering its history of low-carbon electricity generation based on hydropower (van Vliet, 2019, pp. 139–142) and the goal of carbon-neutrality and 100% renewable energy supply by 2050 (Federal Council, 2019). Third, the country is also unlikely to accept losses of (energy) sovereignty, which has been meticulously guarded in past popular votes rejecting Swiss membership in the EU and the European Economic Area (EEA) (Lavenex & Schwok, 2015). Evidence for the existence of an IET in this least-likely case would greatly increase the confidence in our theoretical argument. Observation of an energy policy that maximizes all three objectives would weaken it (Blatter & Haverland, 2012, p. 199).

We hypothesize that Swiss energy policy is constrained by the impossibility to achieve energy security, sustainability, and sovereignty simultaneously. Specifically, we expect that whenever changes in interests, ideas, or institutions increased the priority of one of the three energy policy objectives, this has impeded the achievement of another objective. Our case also exemplifies the role of energy geography and external factors in reinforcing policy constraints within the IET. Switzerland experiences challenges in diversifying its RES, has a relatively small electricity grid and market, and is landlocked. Moreover, Swiss electricity matters are strongly influenced by Swiss-EU relations, which stand at a decisive point. After years of intensive cooperation, political relations between Switzerland and the EU have become tense recently due to unsuccessful negotiations of an institutional framework agreement (Schwok, 2020). Disagreements have permeated into the realm of electricity. Switzerland has been excluded from joint European electricity trading projects and the European Commission threatens to curtail Swiss access to European governance bodies (Hettich et al., 2020). Finally, our case is relevant because electricity dominates Swiss energy policy and relations with its neighbors. Existing research on international energy relations mainly deals with fossil fuels and identified their implications for energy security (Casier, 2011; Mišák, 2019). Yet, electricity-related interdependence differs significantly from oil and gas as new requirements for electricity system flexibility increase cross-border cooperation needs. Furthermore, decarbonization and the electrification of sectors like mobility will reduce demand for fossil fuels. By exploring Swiss electricity policy and its relations with the EU, we capture an energy sector whose importance is set to increase.

Our empirical research is presented as a historical narrative providing analytical explanations. We examine changes in Swiss energy policy over the last decade when debates about the future direction of Swiss energy policy intensified. The descriptive indicators we use to assess the three energy objectives are summarized in Table 2. The analysis draws on official documents, media reports, and academic contributions. Insights gathered from repeated interactions with Swiss and EU decision-makers and stakeholders serve as background information. Recall that we do not examine the causal influence of interests,

Table 2

Operationalization of the three policy choices.

Policy choice	Descriptive indicators
a. Dirty option	<ul style="list-style-type: none"> • Generation adequacy/diversification pursued through unsustainable sources (fossil fuels, nuclear) • Extension of unsustainable generation practices
b. Insecure option	<ul style="list-style-type: none"> • Exclusion of energy sources and/or origins pose risks to uninterrupted supplies and grid stability • High subsidies and a focus on non-competitive energy sources to ensure/diversify supply increase electricity prices
c. Non-autonomous option	<ul style="list-style-type: none"> • Cross-border regulatory and/or policy integration • Transfer of competences and loss of policymaking authority • Domestic application of external energy regulation

Source: authors.

ideas, and institutions on energy policy choices as such but rather the constraining effect of the IET. Potential generalizations of our single case study are addressed in the discussion.

4. Switzerland and the impossible energy trinity

In this part, we empirically explore the IET for Switzerland. We first provide some background on Swiss electricity policy and external influences thereon. We then analyze policy developments related to the IET and empirically illustrate the dirty, insecure, and non-autonomous policy options. We highlight that Switzerland is now at a critical moment of choosing among them.

4.1. The swiss electricity system

Switzerland has a relatively small electricity system next to a large integrated electricity market. Structural differences create an asymmetrical interdependence of Switzerland with the EU. Swiss electricity production consists of over one-third nuclear and almost two-thirds renewable energy (SFOE, 2020, p. 13). The Swiss Energy Strategy 2050 aims to phase-out nuclear and further expand renewables. Switzerland's geography allows for cost-efficient deployment of hydropower, including pumped storage, and PV (Hettich et al., 2020, p. 101; Martínez-Jaramillo et al., 2020, p. 3). The potential of wind and deep geothermal energy is more limited (estimates for 2050: 4.3 TWh and 2 TWh; SFOE, 2021), mainly due to local opposition (Cousse et al., 2020; Thaler et al., 2019, p. 5). Between today and 2050, a stable electricity supply will rely on EU sources (SFOE, 2021), which will reinforce Switzerland's import dependence in winter (Osorio & van Ackere, 2016). Furthermore, Swiss electricity grid elements are an integral part of the European grid, a legacy from times when mainly private actors organized cross-border cooperation (Thaler, 2019). Switzerland has 41 electricity interconnectors with neighboring EU members (Fig. 2). Cost-efficient leveling of fluctuations involves the activation of balancing reserves across these borders (Schillinger, 2020, p. 11).

Despite the close physical interconnectedness of their grids, Switzerland and the EU have never concluded an electricity agreement. Continued EU electricity sector integration widens the regulatory gap and reinforces asymmetric interdependencies. For example, the attractiveness of investments in Swiss RES depends on economic access to the much larger EU electricity market. With an annual consumption of 57.6 TWh in 2018, the Swiss electricity market was more than 50 times smaller than the EU28 market with 2896.3 TWh (Eurostat, 2020; SFOE, 2020, p. 40). As a consequence of the lacking electricity agreement, Switzerland is excluded from EU electricity market coupling and trading platforms, which limits export market opportunities. Access to the EU market would decrease risks for professional investors through marketing opportunities for excess electricity production and storage capacity (Hettich et al., 2020, p. 101). Certainly, Swiss dependence on the EU is not entirely one-sided as Switzerland possesses some structural

Note: Liechtenstein is not shown on this map as it forms part of the Swiss control area.

Fig. 2. Switzerland's interconnectors and location in the European electricity grid. Note: Liechtenstein is not shown on this map as it forms part of the Swiss control area.

Source: authors, based on [Swissgrid \(2015\)](#).

power resources, too ([Hofmann et al., 2022](#)). EU electricity transits flow through its grid, Swiss hydropower could provide storage services to the EU, and Switzerland is a net exporter of electricity in summer. However, as the much smaller partner, Switzerland depends more on the EU in electricity matters than vice versa.

a. The dirty option

Switzerland has long pursued an electricity policy with major 'dirty' elements that prioritized energy sovereignty and security over sustainability. In 2011, more than 40% of its electricity generation came from nuclear power ([SFOE, 2012](#)). Following the Fukushima nuclear accident, the Green Party launched a popular initiative for a nuclear phase-out. Fearing supply shortages and compensation payments, the government developed the Energy Strategy 2050 as a counterproposal that foresaw a nuclear phase-out at slower pace. It prohibits the construction of new nuclear power plants but allows the continued operation of existing reactors until the end of their lifetime ([Federal Council, 2013](#)). As ideational support for an energy transition grew ([Markard et al., 2016](#)), this proposal was adopted by parliament (2016), confirmed in a national referendum (2017), and entered into force in 2018. Yet, present renewable electricity generation capacity is insufficient to compensate for the gradual decommissioning of nuclear power plants. This raises questions about how Switzerland can secure sufficient electricity supply in winter ([ElCom, 2020d](#)). *Ceteris paribus*, the denuclearization will reduce the country's energy security and increase its import dependency.

Today, two variants of a 'dirty option' are considered in Switzerland to ensure energy security and sovereignty. One is to close the supply gap with electricity from fossil sources, currently accounting for less than 1% of domestic production (all from gas; [Kaufmann, 2020](#), pp. 18–21). Already in 2013, the Swiss government noted that, because of the gradual nuclear phase-out, covering demand would likely require the installation of gas power plants ([Federal Council, 2013](#), p. 7633). Recent

studies reflect this assessment, highlighting a need for additional domestic generation capacity ([ElCom, 2020b](#)). This has fueled heated debates with some contributions openly calling for a departure from decarbonized domestic electricity production ([Läuble & Häne, 2020](#); [Stalder, 2020](#)). A widespread argument stresses that one or more new gas power plants could close the gap between phased-out nuclear and new renewable capacity. This would facilitate Switzerland's energy sovereignty by reducing the need to integrate with the EU electricity system. However, resorting to gas would be at odds with Swiss commitments under the Paris Agreement, including the government's carbon neutrality goal for 2050 ([Federal Council, 2021b](#)). While this 'dirty option' faces opposition from environmental groups ([SES, 2020](#); [WWF, 2014](#)), even proponents of an ambitious Swiss energy transition acknowledge that gas may be needed for adequate supplies ([Nordmann, 2019](#)). This tradeoff exemplifies why, in the IET, states pursuing energy security and sovereignty cannot achieve full sustainability. Even worse, this option would reduce electricity import dependence on the EU by increasing import dependence on gas from Russia, Norway, and the EU. One could argue that this partly calls into question the maximization of energy security.

Another 'dirty' option is to extend the remaining lifetime of operative nuclear reactors. This choice is non-sustainable as it would further increase the amount of nuclear waste for which no long-term repository has been designated yet ([Stefanelli et al., 2017](#), p. 73). Interestingly, the Swiss Federal Office of Energy recently started negotiations with utilities on operating existing nuclear power plants ten years longer than currently foreseen ([Meier, 2021](#)). These negotiations have been rooted in concerns about decreasing security of supply if Switzerland was losing access to European electricity trading in the future. Swiss energy law allows for the envisaged extension of operations since it has not specified a maximum lifetime for existing plants and endorses their operation as long as deemed safe. Yet, the final decision is not under direct political control as safety is monitored by the Swiss Federal Nuclear Safety Inspectorate (ENSI), an independent regulatory authority taking

decisions based on technical assessment rather than policy considerations. Moreover, a longer operation of the four remaining reactor blocks has a transitional function only. There are no signs that the ban of new nuclear power stations adopted by Swiss voters could be overturned anytime soon. Without a major change in public opinion, a full-fledged return to this ‘dirty’ option appears unlikely.

b. The insecure option

With its denuclearization strategy, the Swiss government has moved the country from the dirty into the insecure option from 2012 onwards. This appears to be no deliberate choice, considering that official documents have continued to raise concerns about energy security (ElCom, 2020e) and upcoming legislative revisions target this issue (Federal Council, 2021a). Moreover, the Swiss government has negotiated an electricity agreement with the EU that would increase the country’s energy security (FDFA, 2020). The agreement is still pending though because of disagreements with the EU about how far-reaching Switzerland’s political integration should be. Interestingly, institutional questions unrelated to energy are the biggest obstacles in this process. In May 2021, the Swiss government decided to stop the institutional negotiations with the EU. Consequently, a conclusion of the electricity agreement in its current form has become highly unlikely.

Switzerland maintains its (energy) sovereignty at the expense of exclusion from important European coordination processes that are crucial for Swiss energy security. The absence of an electricity agreement with the EU guarantees an independent energy policy but has curtailed Swiss access to European energy governance bodies and participation in market coupling and cross-border capacity coordination (Hettich et al., 2020). As a result, European calculations of cross-border electricity flows currently do not consider Swiss grid elements, which leads to unscheduled flows through the Swiss electricity grid. Unscheduled flows increase congestion of grid infrastructure and jeopardize grid stability. Ensuring network stability under these conditions may require temporary restrictions of Swiss export and import capacities (ElCom, 2020a, p. 58). However, Switzerland is dependent on electricity imports in winter and to close the gap between renewable and phased-out nuclear energy (ElCom, 2020d; Rüdisüli et al., 2019). Scenarios in which these imports cannot be realized point to severe constraints on energy security in terms of access to and availability of electricity.

Adding domestic storage capacities and diversifying the domestic electricity mix through additional renewable capacity would offer a solution compatible with the sustainability objective. However, many countries face limits to energy self-sufficiency. In Switzerland, these limits surface in discussions about clean options for enhancing security of supply. The expansion of wind power is an important measure to secure supply in winter (Suisse Éole, 2020, p. 33) but often faces local opposition fueled by concerns about impacts on landscape and wildlife (Cousse et al., 2020, p. 4). An expansion of hydropower could contribute to uninterrupted supplies but faces technical and environmental obstacles and would require costly infrastructure upgrading (Martínez-Jaramillo et al., 2020; van Baal, 2020). Similarly, even relaxing the sustainability criterion by producing electricity from new domestic gas power plants would result in higher energy costs. Current wholesale prices and CO₂ policy thwart a profitable operation of fossil fuel production capacities in Switzerland (ElCom, 2020e, p. 57). These examples stress that accessibility and availability alone do not guarantee energy security if high costs undermine the affordability of electricity.

c. The non-autonomous option

The non-autonomous option, i.e., prioritizing energy sustainability and security over sovereignty, would require Switzerland to implement the EU *energy acquis*. Under a Swiss-EU electricity agreement, this option would allow Switzerland to participate in European coordination

processes (Hettich et al., 2020) and address current threats to electricity security (e.g., grid congestions) in constructive ways (e.g., cross-border system adequacy coordination). An agreement would also provide for Swiss participation in European electricity market coupling and trading platforms. Cross-border electricity trade would enable Switzerland to focus on cost-efficient RES whilst broadening its electricity consumption mix through imports. Furthermore, full market integration would reduce perceived investment risks and thereby support the expansion of competitive domestic RES, especially PV (Hettich et al., 2020; Hu et al., 2018). Being part of a larger market could also help market Swiss pump storage and bring it back to profitability. Thanks to economies of scale and higher efficiency, Swiss integration into the European electricity market would facilitate energy security and sustainability at lower costs (cf. Martínez-Jaramillo et al., 2020, p. 9).

At the same time, growing electricity trade and cooperation resulting from Switzerland’s integration into the European energy market would create more (inter-)dependencies. Increasing electricity trade under the nuclear phase-out would reinforce Swiss dependence on electricity imports in winter (Osorio & van Ackere, 2016). Higher imports of currently more carbon-intense electricity from the EU would also worsen the carbon footprint of Switzerland’s electricity consumption mix (Messmer & Frischknecht, 2016; Rüdisüli et al., 2019). This is a temporary problem though, considering that the EU is setting itself ambitious decarbonization targets under the European Green Deal (European Commission, 2019). Moreover, EU institutions would make the rules governing the Swiss electricity market. Although Switzerland may gain enhanced access to relevant bodies, a lack of formal veto powers would limit its influence (Hofmann et al., 2022). By rendering an independent energy policy impossible, these developments would reduce Swiss energy sovereignty.

Recently, contradictory developments regarding the non-autonomous option can be observed. On the one hand, emerging practices point in the direction of a less autonomous energy policy. Notably, a technical approach has emerged to ensure a minimum level of Swiss-EU cooperation sufficient to guarantee mutual energy security (ElCom, 2020c). For practical collaborations, this raises questions about the applicable legal framework. While short-term legal workarounds may be available, it seems highly unlikely that Switzerland will be able to use this road without further adjusting to the EU *energy acquis*. On the other hand, the breakdown of the institutional negotiations with the EU questions Switzerland’s readiness to accept major sovereignty losses. Without the institutional framework agreement, prospects of a bilateral electricity agreement are dim. To maintain market access in important areas, the Swiss government seems willing to “adjust autonomously” to important EU legislation—an ideational stretch to energy sovereignty. Its recent proposal to the parliament on completing Swiss electricity market liberalization fits into such a strategy. However, it is highly uncertain how far-reaching autonomous adjustments in Swiss electricity policy will be and whether the EU is willing to play along.

4.2. Summary: at the crossroads of the impossible energy trinity

Our analysis demonstrated that Swiss energy policy is constrained by an IET of energy security, sustainability, and sovereignty. Switzerland pursued a dirty option until 2011 and then moved to a de facto more insecure option (Fig. 3). Today, it once again has three main options (Table 3). An electricity agreement with the EU seems politically dead for now, but we see some early signs for a softer non-autonomous option. At the same time, certain developments point to the other two policy options. Continued unscheduled cross-border electricity flows, higher electricity costs, and ideas to expand domestic RES with massive public subsidies pertain to the insecure option (Vonplon, 2021). Negotiations of the Swiss administration with utilities about a longer operation of existing nuclear power plants and recent conceptual work on a gas power plant may signal a return to the dirty option. At the time of writing, it is unclear which option Switzerland will eventually choose.

Fig. 3. Switzerland in the impossible energy trinity
Source: authors.

Table 3
Swiss energy policy options and their tradeoffs.

Policy option	Energy policy measures	Tradeoffs for policy objectives
a. Dirty option	<ul style="list-style-type: none"> • Add domestic gas-fired electricity generation capacity • Extend operation of existing nuclear power plants • Avoid international energy policy integration 	<ul style="list-style-type: none"> • Increased CO₂ emissions from domestic electricity production • Increased amount of nuclear waste
b. Insecure option	<ul style="list-style-type: none"> • Diversify domestic renewable portfolio by subsidizing less cost-efficient RES • Build up strategic reserve capacity • Avoid international energy policy integration 	<ul style="list-style-type: none"> • High public subsidies and increased electricity prices • Risk of supply shortages and blackouts, costs for grid stabilization measures
c. Non-autonomous option	<ul style="list-style-type: none"> • Conclude electricity agreement with the EU • Close supply gap in winter with electricity imports from the EU 	<ul style="list-style-type: none"> • Mandatory implementation of EU <i>energy acquis</i> • Short-term increase of CO₂ intensity of electricity consumption mix

Source: authors.

The crossroads at which the country currently finds itself represents a choice between major Swiss policy priorities: the pursuit of decarbonization as a contribution to the fight against climate change with its adverse effects on the country's alpine regions; the continuation of a liberal economic policy with limited state intervention and a focus on stability and global competitiveness; and the preservation of sovereignty outside of the EU and EEA. Swiss voters have confirmed all three priorities directly or indirectly in previous referenda. Hence, we expect that the IET will soon force Swiss policymakers and voters to make tough choices.

5. Discussion: priorities, management strategies, and generalizations

Can countries escape the IET? The analysis has shown that while energy policy may change in response to political factors and contested energy geographies, it cannot maximize energy security, sustainability, and sovereignty simultaneously. The only feasible way to escape this

situation requires the large-scale, cost-efficient, and socially accepted deployment of highly diversified RES and flexibility options. Developments in storage technologies and demand-side management may provide new opportunities along these lines. However, only large markets (e.g., for hydrogen or storage) promise diversification at competitive price levels. Based on the dynamics we described, harnessing these potentials presupposes a minimum degree of cross-border integration with repercussions for energy sovereignty. Therefore, many countries cannot easily escape the IET—they can only manage it.

One management strategy might be to “muddle through”. Switzerland could try to avoid tough policy choices by implementing elements of all three options: add some ‘dirty’ generation capacity to the domestic production mix; accept somewhat higher electricity prices in the interest of domestic diversification; and cede sovereignty in matters related to grid operation. For Switzerland, this would require adapting its socio-technical system to spatially reshaped patterns of energy production, transmission, and use. However, the EU as the geopolitically more powerful player appears unwilling to accept Switzerland's integration into its electricity market without adopting the *energy acquis*. A more realistic management strategy is to pursue the non-autonomous option and compensate for the loss of sovereignty by increasing Swiss influence on EU energy policymaking. Switzerland would adopt a smart-state strategy (Grøn & Wivel, 2011) that seeks influence through active participation in European energy governance bodies, the provision of technical expertise in decision-making processes, and coalitions with influential EU members. This would allow Switzerland to pursue a secure and sustainable energy system whose governance it can shape to some extent.

What can the Swiss case teach us about other countries? Around the globe, the energy transition brings fundamental changes to energy infrastructure, spatialities, and policy—often with geopolitical implications. Our conceptualization of an IET explains why many states cannot achieve energy security, sustainability, and sovereignty simultaneously. Despite regulatory integration, EU members have guarded key aspects of energy sovereignty by retaining the right to decide about the sources and structure of their energy supply. Some countries, including France, Hungary, and Sweden, pursue energy security through nuclear power. In line with the IET, this choice creates tradeoffs for energy sustainability (Sovacool et al., 2020). Conversely, Germany's nuclear phase-out and promotion of RES compromise sustainable and secure energy by reinforcing dependencies on domestic coal as well as Russian gas and by increasing energy prices. Overall, the gradual expansion of intermittent RES in the EU increases the need for balancing electricity on a regional scale. This creates (asymmetric) interdependencies between countries and requires additional transfers of authority for cross-border adequacy coordination. We expect that other states will face similar pressures for integration when transitioning to a low-carbon economy, which makes them susceptible to geopolitical power.

Most other European countries have chosen the non-autonomous option too. Members of the Energy Community (countries from the Western Balkans, Ukraine, and Georgia) adopt the EU *energy acquis* in exchange for participation in the trans-European energy market. Energy cooperation and trade have positive effects for security of supply and the expansion of sustainable energy infrastructure (Buschle, 2014). Yet, the adoption of foreign energy regulation undermines sovereignty. Members of the EEA (Norway, Liechtenstein, and Iceland) also adopt EU energy legislation. Norway has used its access to relevant policymaking venues and structural power resources (oil, natural gas, and pumped storage) to influence EU energy policy and customize its implementation to domestic needs (Hofmann et al., 2019). This case exemplifies a smart-state strategy. Thus, the proliferation of the non-autonomous option has partly redrawn Europe's energy map.

The UK is an interesting case since its departure from the EU (‘Brexit’) is associated with efforts to regain sovereignty. As an EU member, it was fully integrated into the EU energy market and bound to

implement supranational energy legislation domestically. Outside of the EU, the UK has regained regulatory autonomy but remains physically tied to the European energy grid via submarine oil, gas, and electricity interconnectors, the latter of which are being significantly expanded (ofgem, 2020). UK energy security will continue to depend on cross-border trade because of its reliance on net electricity imports (Ifelebuge et al., 2017, p. 8 ff.) and its ambitious sustainable energy agenda. The latter includes a coal phase-out and offshore wind expansion with marketing planned via an integrated offshore grid. Irrespective of tense political relations with the European Commission, this requires regulatory harmonization and raises questions about sovereignty aspirations. Similar to Switzerland, without an energy agreement with the EU, the UK may face tradeoffs in its energy policy (Lockwood et al., 2017). Early indicators suggest that it may have to trade off energy security or sustainability against an independent energy policy (Bocquillon, 2021). Again, the interplay of domestic politics and energy geography puts severe constraints on energy policy.

Other countries around the world with asymmetric energy interdependencies may face a similar fate. Mongolia, located between the energy giants Russia and China, produces more than 90% of its electricity from domestic coal (Hans et al., 2020). Turning away from the 'dirty option' without reducing energy security may require integration with neighboring electricity systems. Developing countries in Asia (Bangladesh, Kazakhstan, Vietnam), Africa (Botswana, countries of the West African Power Pool), and South America (Bolivia) that produce power predominantly from fossil fuels may experience comparable integration pressures when attempting to make their electricity supply greener and more secure. Some countries with easy access to seemingly more stable RES, notably hydropower, may find it easier to manage the IET. Yet, climate-related (Bhutan, Costa Rica, Panama, eastern and southern Africa; Conway et al., 2017) and financial risks (Paraguay; Schipani, 2019) have called some success stories into question. These examples suggest that hydropower can reinforce international dependencies and energy policy tradeoffs.

In sum, except for distant island states or states of continental scale (e.g., Australia or the US), countries can maximize sustainable and secure energy only at the expense of energy sovereignty. This is not necessarily problematic, especially where classical conceptions of sovereignty give way to more liberal interpretations that stress mutual benefits of cooperation. For now, however, autonomous control over energy policy seems to remain a key concern in many countries, including EU member states (Bocquillon et al., 2020).

6. Conclusion

In this article, we argued that many states face an IET where they cannot pursue energy security, sustainability, and sovereignty simultaneously. Consequently, they face tough choices in their energy policy strategies. First, they can pursue the dirty option sacrificing sustainability for the benefit of energy security and sovereignty. Second, they can choose the insecure option maximizing sustainability and sovereignty at the expense of energy security. Third, they can select the non-autonomous option achieving secure and sustainable energy by ceding sovereignty through integration with a larger market. We empirically illustrated these options using the revelatory case of Switzerland, an energy policy island surrounded by the EU. The strong physical interconnection of the Swiss and EU electricity systems provides a large potential for balancing the Swiss grid under increasing intermittency from RES. However, this strong interconnection also reinforces the IET. Switzerland currently finds itself at the crossroads of selecting one of the policy options.

Our article does not offer any easy prescriptions on which strategy a state should choose. Theoretically, we expect that the non-autonomous option is the most likely outcome in contexts where no major political disagreements block integration with larger markets. The reason is twofold: First, energy security is almost a natural priority as it is

essential for the competitiveness of open economies. In an ever more electrified and digitized society, the importance of secure electricity is set to increase further. Second, sustainability increasingly gains in relevance. Public and international pressure to decarbonize and/or denuclearize render the dirty option unlikely. By contrast, we see potential for ceding energy sovereignty when accompanied by efforts to shape policies of the entity to which competences are transferred. Such a smart-influence strategy can be a sensible approach to realize environmental and economic objectives. It remains an open question though whether and how voters and legislators can be persuaded to transfer control over parts of their country's energy policy to another state or group of states, especially as calls for a strong nation-state are gaining popularity in many places. One potentially useful argument is to consider the structural power that states may gain from a greater interconnection with neighbors. Switzerland with its large natural storage capacity and central position for electricity transits that are critical for EU electricity market integration is an instructive example (Hofmann et al., 2022). In the medium to long run, the strategic addition of new grid infrastructure as well as storage and generation capacity may help states to reduce asymmetric dependencies.

Our findings speak to literature on the political economy of RES, the spatial dimensions of energy transition, and network interdependencies. The transition to an RES-based electricity generation challenges energy sovereignty by increasing demand for regional integration of electricity grids. Cross-border electricity interconnectors require joint network and market governance (Ringler et al., 2017). Interlinkages between cross-border electricity grid governance and (sub-)national transition processes underscore the importance of scale in energy geography (Baka & Vaishnava, 2020). Moreover, asymmetric interdependencies render countries more susceptible to geopolitical pressures (Fischhendler et al., 2016; Westphal et al., 2021). Our model echoes research into network interdependencies as control over critical energy infrastructure determines countries' power relationships in their governance (Farrell & Newman, 2019; Thaler, 2019). Especially, we showed that lack of network control forces countries to make tough choices between energy security, sustainability, and sovereignty. We encourage future research to explore how countries other than Switzerland are coping with this situation.

Declaration of competing interest

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

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