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

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

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Abstract

This article explores energy policy trade-offs faced by small states in cross-border electricity systems. We develop the concept of an impossible energy trinity which posits that small states in the energy transition cannot simultaneously achieve energy security, sustainability, and sovereignty. Based on a relational definition of energy smallness, we argue that small states have three options to cope with the intermittency of domestic electricity production from renewables and the resulting challenges for security of supply and grid stability. The dirty option resorts to generation from non-sustainable energy 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 an integration with the electricity grids and markets of larger neighbors. We empirically illustrate our novel concept using the case of Switzerland, which currently finds itself at the crossroads of the three options. We show that the country has to choose whether it wants to add gas-fired generation capacities, accept grid instabilities and higher electricity prices, or further integrate with the EU electricity market and rule set. We discuss possibilities for managing the impossible energy trinity as well as possible generalizations beyond the Swiss case. We conclude that considering public pressure for decarbonization and economic pressure to maintain a secure energy supply, the non-autonomous option will currently be the most likely policy option in many small states. This will reinforce the regional integration of electricity grids and the related power relationships.

Introduction

What trade-offs do small states face in the pursuit of a secure and sustainable energy supply? The transition towards an energy system based on renewable sources poses new challenges for energy security. The intermittency of renewable electricity supply requires a diversification of energy sources as well as flexibility options. As a result, small countries face increasing pressures to integrate their electricity systems and markets with their neighbors. Cross-border electricity systems support *energy security* by providing access to flexible balancing power and levelling energy demand and supply across larger areas. Cross-border electricity markets also promote *sustainable energy* by creating larger markets that allow for the exploitation of competitive advantages and economies of scale, thereby attracting green investments. Yet, system and market integration presuppose the adoption of common rules as well as supranational oversight and enforcement mechanisms. In this context, lopsided interdependencies with larger neighbors can coerce small states to transfer authority over domestic energy rules to foreign institutions. Conversely, the preservation of full control undermines such integration, thereby compromising energy security or sustainability in small countries.

In this paper, we argue that this constellation points to an 'impossible energy trinity' for small states: energy security, sustainable energy, and full sovereignty cannot be achieved simultaneously.

We investigate this claim using evidence from Switzerland, which is physically highly interconnected with the electricity systems of neighboring member states of the European Union (EU). The case study reveals that many pending techno-economic decisions in the Swiss energy transition are closely linked to unresolved questions about the future electricity relationship with the EU. We show that Switzerland currently finds itself at a branching point of two future pathways: Electricity cooperation with the EU would increase Swiss energy security but lead to contentious interferences into its sovereignty, whereas the preservation of Swiss sovereignty would weaken efforts to increase the share of renewables and maintain a secure electricity supply. The Swiss case suggests that the transition to a secure and renewable-based energy system increases pressures on small states to engage in cross-border cooperation, which may trigger domestic conflict about competing visions of sovereignty.

Our paper links so far disconnected research streams on domestic energy transitions, EU-third country energy relations, and the role of small states in international relations. Multidisciplinary scholarship has identified technical, economic, and political challenges in domestic energy transitions, including the volatility of energy production from renewables (Sinn, 2017), barriers to investments in renewables (Hu et al., 2018), and issues of societal acceptance (Wüstenhagen et al., 2007). Research of political scientists on EU-third country energy governance has highlighted structural interdependencies between the Union and its neighbors and discussed the resulting power relations (Godzimirski, 2019; Hofmann et al., 2019; Lavenex, 2004). With respect to small states, international relations scholars have examined foreign policy choices vis-à-vis great powers (Gvalia et al., 2013; Haugevik & Rieker, 2017) as well as "smart" strategies for exerting influence in the EU (Arter, 2000; Grøn & Wivel, 2011) and in international negotiations (Bueger & Wivel, 2018; Schulz et al., 2017). We bring these research streams together by exploring the domestic and foreign policy tradeoffs that a small state in the EU's vicinity faces in its domestic energy transition. Our main contribution to energy studies is the argument that, for small states, a transition to an energy system based on renewables is likely to impose sovereignty costs and increase the level of energy policy integration with their neighbors.

In the next section, we theorize the tradeoffs of an energy transition in small states introducing the novel concept of an "impossible energy trinity". We then empirically illustrate this impossible energy trinity by analyzing the current energy policy debates in Switzerland. Finally, we discuss to what extent our framework might be applicable to other small states in Europe and beyond. We conclude that while the impossible energy trinity puts pressure on the energy sovereignty of small states, smart influence strategies may compensate for some of the sovereignty losses.

Conceptualizing the impossible energy trinity

In this part, we develop our conceptual argument about an "impossible energy trinity" that small states are confronted with in the energy transition. To begin with, we define what we mean by small states by providing a relational operationalization of "energy smallness". We then explain how energy smallness creates an impossible energy trinity in which countries face a tradeoff between energy security, sustainability, and sovereignty. Next, we define these three objectives and operationalize them. We end this part by reflecting on possibilities to manage the tradeoff between these three objectives.

Energy smallness

Our argument focuses on small states. International relations research has defined small states mainly in terms of their limited material capabilities. Classical indicators are the size of a country's population, territory, GDP, and military expenditures (cf. Thorhallsson & Wivel, 2006, pp. 653–654). One major problem with these indicators is that they are not issue-sensitive. While the size of a country's population and economy may match its energy capabilities and resources, this relationship is by no means self-evident. For instance, Norway is clearly a small state in Europe if measured by the size of its population and economy (Sverdrup, 2014, p. 151). Yet, Norway is also considered an "energy giant" on the continent because of its richness in fossil and renewable energy resources (Szulecki et al., 2016, p. 559). Another examples is Paraguay. Although a small and relatively poor country on the South-American continent, it has become one of the largest net-exporters of electricity in the world thanks to significant hydropower resources (Folch, 2019). Thus, indicators of smallness need to be issue-specific.

To capture smallness in the realm of energy, we suggest an operationalization that brings in energy geography. One major aspect here is to what extent a country's geography allows for a cost-efficient deployment of diverse renewable energy sources. This includes the number of suitable locations for wind turbines, the number of yearly sunshine hours that can be harnessed by photovoltaics, the amount of water resources available for hydropower generation, available resources for energy from biomass, as well as the ease with which geothermal energy can be accessed and used. Another major aspect is to what extent a country's electricity grid is large and resilient enough to efficiently balance supply and demand fluctuations across regions and via access to storage options. Additionally, we assume that electricity market size has implications for a country's capacity to attract investments in renewable energy projects. Given our interest in energy rather than climate more broadly, we do not consider a country's share in global greenhouse gas emissions which has been used as indicator to identify small states in climate politics (Carter et al., 2019, pp. 981–982).

Although the above-mentioned criteria are a useful basis for an energy-specific definition of smallness, their operationalization in absolute terms is problematic. The key question is where to set the cut-off point between small and big states. Scholars would have to define a level of energy autarky that is sufficient for escaping smallness. But which diversity in renewable energy resources, grid size, and market size would be sufficient to qualify as a big state? Existing small state research has shown that a definition of absolute cut-off points always remains somewhat arbitrary (Thorhallsson & Wivel, 2006, pp. 653–654). We therefore follow a different approach.

A more fruitful operationalization of energy smallness can be achieved by adopting a relational approach. Long (2017) has argued that smallness should not be conceived of as a property but rather as a relationship. In that sense, smallness is the result of a (partial) dependence on another state. This dependence does not need to be entirely one-sided; it may rather take the form of asymmetric interdependence. As Keohane and Nye (1989, pp. 10–11) have famously noted, "it is *asymmetries* in dependence that are most likely to provide sources of influence for actors in their dealings with one another" (emphasis in the original). Consequently, we consider that country A is comparatively small when depending much more on country B than B depends on A. This understanding can be applied to our energy-specific notion of smallness. Small states depend on other states or integrated markets of groups of states for full access to: diverse and cost-efficient renewable energy sources; an electricity grid that can efficiently balance supply and demand fluctuations; international electricity trading platforms for day-ahead, real-time, and balancing markets; and marketing opportunities that contribute to attracting investments into renewable energy projects. This operationalization circumvents the need to define fixed cut-off points by assessing differences in the energy geography of countries and the patterns of (inter-)dependence resulting from them.

Three energy policy objectives: Security, sustainability, and sovereignty

We posit that the basic orientation of a country's energy policy can be usefully captured in terms of the three objectives of energy security, sustainability, and sovereignty. All these terms have figured prominently in existing energy research and there is no shortage of competing conceptualizations. In turn, we reiterate why these three objectives are central to energy policy and provide the definitions on which our argument builds.

The notion of energy security has become ubiquitous in discussions about energy governance and climate change but is the concept which requires most elaboration. Policy documents, reports, and academic scholarship 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 a degree of energy self-sufficiency. Despite the pervasiveness in the political discourse, energy security remains an elusive concept (Ang et al., 2015; cf. Chester, 2010). In this article, we operationalize energy security based on the four A's: availability, accessibility, affordability and acceptability (Cherp & Jewell, 2014; Jewell et al., 2014). Unlike most definitions that implicitly refer to energy security in a fossil fuel world, this approach can accommodate contextual novelties of the post-carbon era, including the unparalleled use of energy from renewable sources and the electrification of energy system. We refer to accessibility, the first A, as direct access to sufficient primary energy sources to meet demand. Renewable energy sources like wind, solar, and hydropower are more equally accessible across the globe than fossil fuel resources. Yet, access is only a necessary but not sufficient condition for energy security as it does not guarantee availability. The second A, availability, denotes uninterrupted energy from domestic and external sources. This A gains in relevance as the share of electricity from intermittent renewable sources in the energy mix is growing. Unlike other energy carriers, electricity cannot be stored cheaply and easily at present. Resilient infrastructure, efficient markets, and an appropriate regulatory framework are therefore critical. Depending on domestic access to (renewable) energy resources and the conditions under which they can be harnessed, the provision of uninterrupted electricity can be extremely costly. Affordability, the third A, stresses the supply of energy at competitive prices levels. These three A's reflect the core of the IEA's energy security definition: "ensuring the uninterrupted availability of energy sources at an affordable price" (IEA, 2020). The fourth A, acceptability, is often used as a synonym for sustainability (Chester, 2010, p. 890) and has been criticized for a lack of specificity in relation to energy security (Cherp & Jewell, 2014, p. 417). Since we conceptualize sustainability as a separate corner of the impossible energy trinity, we do not include it in our definition of energy security. Rather, we understand acceptability in terms of the social acceptance of energy sources which has an impact on how much of their potential can be realized (Wüstenhagen et al., 2007). In short, we refer to energy security as accessible, available, affordable, and acceptable energy.

Sustainable energy denotes the pursuit of a carbon-neutral energy system based on the use of renewable sources. Renewable energy sources "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 fuel like oil, gas, and coal, as well as nuclear power. The exclusion of nuclear power from sustainable energy may seem odd, considering that countries like Finland, France, or the UK expressly pursue decarbonization strategies relying on the combined use of nuclear and renewables (Teräväinen et al., 2011). However, recent large-n research has found that nuclear and renewable energy tend to crowd out each other and that renewable-based strategies lead to lower national carbon emissions than nuclear-based strategies (Sovacool et al., 2020). In combination with unresolved questions on nuclear waste disposal, these findings justify an exclusion of nuclear power from our definition of sustainable energy. Furthermore, we note that truly sustainable energy encompasses carbon neutrality both in domestic electricity generation and in the consumption mix, excluding fossil-fuel or nuclear generated electricity imports.

Sovereignty can generally be defined as "the power of a country to control its own government" (Cambridge Dictionary, 2020). Within energy studies energy sovereignty has been associated with different meanings, including the protection from external disruptions (Cherp et al., 2012) and protectionist policies against regulatory competition (Crossley, 2013). Resembling the original meaning of sovereignty, both perspectives stress the absence of outside interference in domestic energy governance. More recently, scholars have also linked energy sovereignty to more autonomous decision-making by consumers and communities about the energy system they use (Laldjebaev et al., 2015; Schelly et al., 2020). In this article, we use the term in the more traditional, state-centric meaning reflected in the first two perspectives. We thus define energy sovereignty as a country's ability to independently decide about its structure and sources of energy supply (the 'hardware' of energy governance) and to formulate and implement its energy policy, the rules governing its energy market, and the operation of its energy system (the 'software' of energy governance). Table 1 summarizes our definitions of energy security, sustainability, and sovereignty.

Table 1: Definitional elements of energy security, sustainable energy, and energy sovereignty

Concept	Main definitional elements
Energy security	• Accessibility: access to sufficient energy sources • Availability: uninterrupted provision of energy supplies • Affordability: energy at competitive price levels • Acceptability: social acceptance of realizing renewable potential
Sustainable energy	• Carbon-neutral electricity generation and consumption mixes • Exclusion of nuclear energy
Energy sovereignty	• 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

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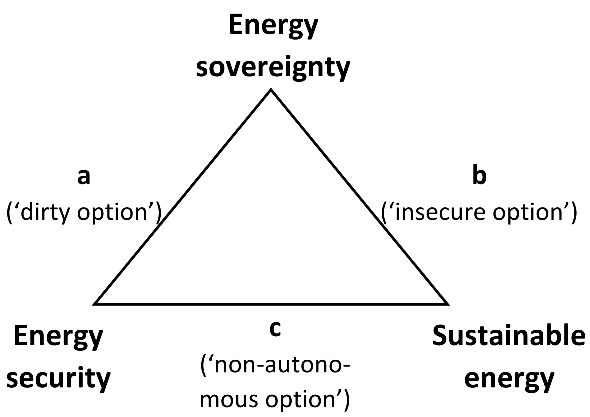
The impossible energy trinity for small states

We posit that an impossible energy trinity exists in the electricity policy of small states. We argue that small states face tradeoffs between the three objectives of energy security, sustainability, and sovereignty. The main reason for this is the need to integrate into cross-border electricity systems when pursuing a transition towards a renewable-based energy system. Electricity generation from renewables is much more volatile than from fossil fuels, implying that electricity systems will have to be adapted to ensure uninterrupted availability of electricity (Sinn, 2017). The higher volatility from growing shares of renewable electricity increases the need for differentiated portfolios of renewables to ensure stable supply. For instance, sufficient generation capacity from hydropower and photovoltaics is needed in case the wind is not blowing, and vice versa. Storage solutions and, to a limited extent, demand-side management help to buffer intermittent electricity generation from renewables (Sinn, 2017). Maintaining grid stability in a renewable energy world is thus eased by geographically diversified resources and storage options as well as possibilities to balance demand and supply. Large electricity markets, like the EU, may have all prerequisites for satisfying these needs in cost-efficient ways. Their energy resources are sufficiently diverse to compensate for low production from one source. Their electricity grids are (becoming) resilient enough to enable an efficient use of dispersed storages and even out supply and demand fluctuations. Additionally, the large market size reduces commercial risks for professional investors in renewable energy development.

Small states are in a less favorable position for building up differentiated renewable portfolios, balancing grids in a renewable energy system, and attracting green investments. They can efficiently deploy certain renewable energy sources but rely on other countries for a diversified supply. Notably, they depend on cross-border electricity systems to import electricity from renewable sources that cannot be harnessed in cost-effective ways domestically. Moreover, small states alone have a too limited electricity system size to efficiently level supply and demand differences. They depend on electricity interconnections with neighboring countries to balance their grid. Smallness also results from risk-related constraints on investments in renewables. Investment decisions of professional investors depend on business opportunities for selling domestic excess production from renewables (Hettich et al., 2020, p. 101). These opportunities are limited when a country lacks a large electricity market or access to it. All these elements suggest that, in their undertaking to efficiently manage the domestic energy transition, small states depend on cross-border interconnections with other states or groups of states that may be in a better position regarding diversified renewables, balancing power, and market size. This does not exclude the possibility that larger states may partially depend on smaller states in other respects (e.g., electricity transits). Yet, the important point is that the interdependence we are describing is asymmetrical and disadvantages the smaller state.

For small states, asymmetrical interdependence creates an "impossible energy trinity". To support their energy security and sustainability, small states may want to integrate into cross-border electricity systems. Such integration promises access to flexible balancing power, cost-efficient levelling of demand and supply fluctuations, and marketing opportunities for excess electricity from investments in renewables. However, system and market integration comes at a price. It usually requires the adoption of common rules and supranational monitoring and enforcement mechanisms. This may force small states to cede sovereignty by transferring authority over domestic energy rules to the foreign institutions of their larger partner. Conversely, the preservation of full control undermines integration, thereby compromising energy security and/or sustainability in small countries. It follows that small states cannot simultaneously achieve the three objectives of energy security, sustainable energy, and energy sovereignty. We call this "the impossible energy trinity" in the energy transition of small states.

Graph 1: The impossible energy trinity



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The concept of an impossible trinity has its origins in international economics. Developed independently by the economists Robert Alexander Mundell and John Marcus Fleming in the early 1960s and therefore also known as the Mundell-Fleming model, it asserts that it is impossible to have at the same time a fixed foreign exchange rate, free capital movement, and an independent monetary policy. This hypothesis has been supported by numerous empirical studies that found governments to fail in trying to pursue all three goals simultaneously (Boughton, 2003). The main conclusion of the impossible trinity is thus that a central bank has to forego one of the three objectives by choosing one out of three options: (1) seek a stable exchange rate and free capital flows, but sacrifice an independent monetary policy; (2) pursue an independent monetary policy and free capital flows, but give up on a stable exchange rate; or (3) uphold a stable exchange rate and an independent monetary policy, but relinquish free capital flows. While we do not wish to delve into political economy here, we adopt the terminology of an "impossible trinity" as a useful metaphor for capturing our theoretical argument.

Reconciling or managing the impossible energy trinity?

The impossible energy trinity is conceptually different from the so-called "energy trilemma". The energy trilemma highlights the incompatibility of simultaneously achieving energy security, energy equity, and environmental sustainability. Gunningham (2013, p. 185) notes two different perspectives on the trilemma. The first one stresses substantial obstacles to ensure energy security, alleviate energy poverty, and mitigate climate change concurrently. Progress in achieving all objectives is exceptional, but at least in principle the trilemma can be resolved. This view is underpinned by empirical data from the World Energy Council which ranks countries according to their success in achieving the three objectives (WEC, 2019). The second perspective assumes that only two of the three objectives can be achieved at the same time. The trilemma thus can only be managed through dedicated policy choices. Our concept of an impossible energy trinity differs from the trilemma by considering energy sovereignty instead of energy equity and by being applicable only to small states in cross-border electricity systems.

The impossible energy trinity is 'impossible' in the sense that it cannot be resolved but only be managed. Similar to the Mundell-Fleming model in political economy, the three policy objectives of energy security, sustainability, and sovereignty are mutually incompatible. Put differently, policymakers will always be faced with a choice for two among the three objectives. This leaves them with three policy options, depicted in graph 1 as a, b, and c. The 'dirty option' (a) maintains both energy security and sovereignty by relaxing sustainability objectives. The 'insecure option' (b) maximizes sustainability and energy sovereignty at the expense of energy security. The 'non-autonomous option' (c) pursues secure and sustainable energy but sacrifices sovereignty. We now turn to exploring these three options empirically.

Switzerland and the impossible energy trinity

In this part, we use the case of Switzerland and its electricity relations with the EU to illustrate the impossible energy trinity faced by small states in cross-border electricity systems. In the beginning, we summarize the properties of the Swiss case and show why it is an interesting addition to existing case studies. We then analyze recent developments in the Swiss energy policy discourse that relate to the impossible energy trinity and present empirical illustrations for the dirty, insecure, and non-autonomous policy options. Finally, we summarize this part by highlighting that Switzerland currently is at a critical moment of choosing among these options.

Properties of the Swiss case

Switzerland is an interesting case for an empirical illustration of the impossible energy trinity for three reasons. First, with its EU neighborhood, Switzerland exemplifies a small state in the vicinity of a large integrated electricity market. The energy smallness of Switzerland is rooted in a pattern of asymmetrical interdependence with the EU. The current Swiss electricity production mix consists of over one third nuclear energy and almost two thirds renewable energy sources (BFE, 2020, p. 13). The Swiss Energy Strategy 2050 foresees a phase-out of nuclear power and further expansion of renewables. Switzerland's geography allows for the 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 due to high costs, local opposition, or technical challenges

(Thaler et al., 2019, p. 5; VSE, 2020). A stable future supply with electricity from renewables thus relies on sources in the neighboring EU. This will reinforce the present import dependence of Switzerland in winter (Osorio & van Ackere, 2016). Furthermore, Swiss electricity grid elements are an integral part of the European electricity grid. A cost-efficient levelling of fluctuations involves the activation of balancing reserves across borders within Europe (Schillinger, 2020, p. 11).

Switzerland's energy smallness also results from the fact that the attractiveness of investments in Swiss renewable energy sources 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 that of the EU28 where 2896.3 TWh were consumed (BFE, 2020, p. 40; Eurostat, 2020). Low electricity prices in recent years have limited possibilities for trading excess electricity generated from Swiss hydropower sources on the EU market (Gisler et al., 2018, p. 10). The increasing exclusion of Switzerland from EU trading platforms, which is due to the lack of an electricity agreement between Switzerland and the EU, is further limiting export market opportunities. Swiss access to the EU would decrease risks for professional investors by creating additional marketing opportunities for excess electricity production and storage capacity (Hettich et al., 2020, p. 101). Certainly, Switzerland's dependence on the EU is not entirely one-sided as it possesses some structural power resources, too (Hofmann et al., forthcoming). Large amounts of EU electricity transits flow through its grid, Swiss hydropower has potential for providing storage services to the EU market, and Switzerland is a net exporter of electricity in summer. However, the important point here is that, in the area of energy, Switzerland depends more on the EU than the other way around.

Second, Switzerland is an instructive case because Swiss-EU energy relations are dominated by electricity matters. Existing research on the energy relations of small states mainly focuses on fossil fuels. Research on the Baltic states has stressed the dependence on oil and gas supplies from their big neighbor Russia (Crandall, 2014, pp. 40–44; Lamoreaux, 2014, pp. 574–575). Research on fossil fuel supplier Norway has taken the reverse perspective and outlined how hydrocarbon resources can empower a small state (Godzimirski, 2019). While these are important topics, they are different from patterns of interdependence encountered in cross-border electricity systems. Because of the energy transition, electricity systems are subject to rapid transformations. New requirements on system flexibility increase the need for cross-border cooperation involving at least some degree of mutual dependence. Moreover, electrification of sectors like mobility will reduce the demand for fossil fuels. By exploring electricity relations between Switzerland and the EU, we capture an energy sector whose importance is set to increase in the future.

Third, Swiss-EU relations are neither clearly conflict-prone nor exclusively cooperative. Some previous research on small state energy policy has focused on EU member states like Estonia, Finland, and Hungary in a context of tense EU-Russian relations (Aalto et al., 2017; Crandall, 2014). Others have examined cooperative relations, for instance, between Norway and the EU in the framework of the European Economic Area (EEA; Austvik, 2019; Godzimirski, 2019) or between small Southeast European states and the EU in the Energy Community (Buschle, 2014; Prange-Gstöhl, 2009). The broader political relations between Switzerland and the EU are generally characterized by cooperation but have become increasingly tense during the negotiations of a new bilateral institutional framework agreement. For instance, the EU has punished Switzerland for a perceived lack of progress on the new agreement with unfriendly measures in areas like telecommunications (Mäder, 2019), stock markets (Schmutz, 2019), and health (Mäder, 2020). Disagreements have also permeated into the realm of electricity. Switzerland has been excluded from joint European electricity trading projects and the European Commission threatens to curtail existing Swiss access to European governance bodies (Hettich et al., 2020). Thus, Swiss-EU electricity relations seem to stand at a decisive point. The following sections will show that Switzerland has to choose which option of the impossible energy trinity it wants to pursue.

a. The dirty option

The first option for small states facing the impossible energy trinity is the 'dirty option'. Here, policy-makers prioritize energy sovereignty and energy security over sustainable energy. While energy sovereignty excludes interferences from outside, it entails consequences for international energy relations. The reason is that cross-border electricity systems require significant cooperation on the regulations governing international energy flows. This includes the definition and implementation of shared rules for system operation, energy trade and markets, as well as enforcement and litigation mechanisms. As the number of countries participating in a cross-border electricity system increases, so does the diversity of interests that have to be reconciled. Cooperation therefore necessitates mutual concessions and compromise. Here, as in any international negotiation, powerful states will find it easier to have their interests reflected in the agreements. Small states will typically have less power resources at their disposal, likely putting them in the position of a rule-taker. Rejecting this external interference in the pursuit of full energy sovereignty comes at a cost. Since the adoption of shared rules is a precondition for the functioning of cross-border electricity systems, their rejection automatically entails an exclusion from (or at least severe constraints on the participation in) these systems. Energy sovereignty and full participation in cross-border electricity systems are thus mutually incompatible for small states.

Non-participation in international energy governance sets limits to cross-border energy trade. Pursuing energy security, a country will then have to satisfy its electricity demand through domestic generation. As noted previously, a small country is less favorably placed to have diversified renewable energy or natural storage options at its disposal to guarantee accessible and available electricity. This disadvantage could partly be compensated through significant public financial support for renewable generation or storage technologies. Such an intervention could ensure adequate supplies but would raise electricity prices, undermining the 'affordability' criterion of energy security. Maintaining competitive electricity prices would require falling back on cheap conventional energy carriers that can easily be stored to provide accessible, available, and affordable electricity. However, the generation of electricity from fossil fuel or nuclear sources is incompatible with the objective of sustainable energy. This explains why the prioritization of energy sovereignty and energy security by small states ultimately is a 'dirty option'.

In Switzerland, two variants of a 'dirty option' have been considered to ensure energy security and sovereignty. Energy security is a critical issue due to the country's import dependency in winter months. Despite this import dependence, Swiss voters in a national referendum in 2017 adopted a prohibition of the construction of new nuclear power plants. This means that nuclear power will become phased-out when existing power plants reach the end of their lifetime. The nuclear phase-out and currently still insufficient installations of new capacity from renewables raise questions about how Switzerland can secure sufficient supply in winter (ElCom, 2020c). One solution to secure enough base load could be to extend the remaining lifetime of the still operative nuclear power plants. This is a non-sustainable option because it would further increase the amount of nuclear waste for which no long-term repository has been designated in Switzerland yet (Stefanelli et al., 2017, p. 73). Swiss energy law already makes partial use of this nuclear power option though because it has not set any fixed maximum lifetime for existing plants. Instead, they can be operated longer than initially envisaged by the utilities if still deemed safe. The safety of nuclear power stations is controlled by the Swiss Federal Nuclear Safety Inspectorate (ENSI), which is an independent regulatory authority taking decisions based on technical assessment rather than policy considerations. Hence, while relevant in terms of security of supply, this 'dirty option' is currently not under direct political control.

Another 'dirty option' would be to close the supply gap with electricity from fossil sources. Already in 2013, the Swiss Federal Council made clear that, in light of the gradual phase-out of nuclear power, covering demand would likely require the installation of gas-fired combined cycle power plants (Bundesrat, 2013, p. 7633). Recent studies broadly reflect this assessment, highlighting a need for additional domestic generation capacity (ElCom, 2020b). This has fueled heated political and public debates with some contributions openly calling for a departure from decarbonized domestic electricity production (Läuble & Häne, 2020; Stalder, 2020). An increasingly widespread argument stresses that the construction of one or more gas power plants could close the gap between renewables and phased-out nuclear power by producing the necessary base load to meet Swiss electricity demand. This would reduce Switzerland's electricity import dependency and thereby facilitate a sovereign energy policy.

Currently, the Swiss electricity production mix has a very low carbon intensity as it does not include generation from gas, oil, or coal (Messmer & Frischknecht, 2016). The construction of power plants fueled with natural gas would therefore increase the greenhouse gas footprint of Swiss electricity production and constitute a significant step back in terms of carbon neutrality. Unsurprisingly, this 'dirty option' faces opposition from environmental groups (SES, 2020; WWF, 2014). Yet, even strong proponents of an ambitious domestic energy transition acknowledge that gas power plants may be needed to ensure adequate supplies (Nordmann, 2019). This trade-off exemplifies that, in the impossible energy trinity, small states pursuing energy security and sovereignty cannot achieve full sustainability.

b. The insecure option

Small states facing the impossible energy trinity can also opt for the 'insecure option'. This choice prioritizes energy sovereignty and sustainability over energy security. As demonstrated in the 'dirty option', preserving energy sovereignty results in constraints on participation in cross-border electricity systems or even full exclusion from them. This causes two types of costs for small states. With an electricity transmission grid physically interconnected to those of neighboring countries, insufficient consideration in network operation can undermine domestic system stability. The reason is that the small state lacks information and control over cross-border electricity flows. This leads to unscheduled flows that can put significant stress on the transmission grid. Moreover, non-cooperation sets limits to international electricity trade, for instance, by preventing the development and operation of joint trading platforms. The simultaneous pursuit of sustainable energy implies that balancing the intermittency of domestic renewable energy generation through conventional 'dirty' electricity generation is no viable strategy.

The insecure option features two possible pathways. First, a small country could only focus on those renewable generation and storage options in which it has a comparative advantage. This may ensure low electricity prices but would risk supply shortage and blackouts. An undiversified energy mix cannot compensate the intermittency of renewables, undermining uninterrupted availability of electricity. Given the importance of continuous energy supplies for modern societies and economies, decision-makers are unlikely to choose this pathway. Second, a small country could ensure uninterrupted electricity supplies through substantial investments in diversified renewable generation capacity and storage options. Comparative advantages in these technologies are typically limited and investors may perceive investments in small markets with uncertain returns as risky. Consequently, only significant public subsidies could incentivize these green investments. Subsidies lead to extra costs that would increase domestic electricity prices and reduce the affordability of energy. The pursuit of energy sovereignty and sustainable energy therefore constitutes an 'insecure option' impairing energy security objectives.

Swiss energy sovereignty is currently retained at the expense of an exclusion from important European coordination processes. The absence of an electricity agreement with the EU guarantees an independent domestic energy policy but has resulted in a loss of Swiss access to European bodies of energy governance (Hettich et al., 2020). As a consequence, Swiss grid elements are not considered in European calculations of cross-border electricity flows. This lack of cooperation contributes to unscheduled flows through the Swiss electricity grid which increase congestion of grid infrastructure and jeopardize grid stability. This may necessitate the temporary restriction of Swiss export and import capacities to ensure network stability (ElCom, 2020a, p. 58). However, Switzerland is dependent on electricity imports in winter and to close the gap between renewable production and phased-out nuclear energy (ElCom, 2020c; 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 the installation of additional renewable capacity would offer a solution compatible with the sustainability objective. However, energy smallness sets limits to energy self-sufficiency. In Switzerland, these limits surface in discussions around different clean options for enhancing security of supply. A strategic reserve based on hydropower addresses the problem only in the short-term but is inappropriate for ensuring long-term energy security. Furthermore, larger reserves that could safeguard uninterrupted electricity supplies more effectively would be proportionally more costly (van Baal, 2020). The example stresses that accessibility and availability alone do not guarantee energy security if high costs undermine the affordability of electricity.

Affordability, together with acceptability, is also the Achilles' heel of energy security when seeking to guarantee supply through a diversification of the domestic renewable electricity mix. The expansion of wind power in Switzerland has a high potential of 30 TWh until 2050 and is considered an important measure to secure supply in winter (Suisse Eole, 2020, pp. 30, 33). However, wind power projects often face local opposition, contributing to a very long permit application time for large wind energy projects of about 10 years—twice as long as in the EU (Wüstenhagen et al., 2017, p. 11). Long administrative processes tend to scare away investors, so that presently less than 40 large wind power plants exist which together accounted for only 0.22% of the domestic electricity production in 2019 (Kaufmann, 2020, pp. 6, 32). It is thus doubtful that Switzerland will see a substantial rise in wind power projects within the next years. Finally, even relaxing the sustainability criterion by producing electricity from a new domestic gas power plant would result in higher energy costs. Current wholesale prices and CO2 policy thwart a profitable operation of fossil fuel production capacities in Switzerland (ElCom, 2020d, p. 57).

c. The non-autonomous option

The third option for small states facing the impossible energy trinity is the 'non-autonomous option'. Here, policymakers focus on energy security and sustainability at the expense of energy sovereignty. Electricity system integration allows small states to exploit their domestic comparative advantage in electricity generation and storage options and balance intermittent electricity supplies through cross-border electricity trade. This facilitates energy security through available and accessible electricity at affordable prices. Electricity trade also helps exploiting the renewable energy and storage potential. Efficient cross-border markets for renewable electricity reduce the need for backup generation capacity from dirty sources, promoting a system-wide transition to sustainable energy. As mentioned previously, electricity system integration requires harmonized regulation. Small states pursuing energy security and sustainability through cross-border cooperation thus have to accept limitations to their energy sovereignty.

The non-autonomous option would require Switzerland to implement the EU *energy acquis*, the EU's accumulated legislation, legal acts, and court decisions in the field of energy. Under an electricity agreement with the EU, this would allow Switzerland to participate in important European coordination processes (Hettich et al., 2020). In these processes, issues like grid congestion that currently threaten Swiss electricity security by limiting its import capacities could be addressed in a constructive way. Cooperation would also facilitate cross-border trade, enabling Switzerland to focus on those renewables in which it has a competitive advantage whilst broadening the electricity consumption mix through imports. Furthermore, full integration in the European electricity market would reduce perceived investment risks of institutional investors and thus facilitate the expansion of domestic competitive renewables, especially photovoltaic (Hettich et al., 2020). Being part of a larger market could also help market Swiss pump storage and bring it back to profitability. Overall, the integration in a larger electricity market would materialize economies of scale and increase the efficiency of the Swiss energy transition. This promises the achievement of energy security and sustainability at lower costs.

At the same time, the increase in electricity trade and cooperation resulting from Switzerland's integration in the European energy market would also create more (inter-)dependencies. An increase in electricity trade under the nuclear phase-out will reinforce Switzerland's dependence on electricity imports in winter (Osorio & van Ackere, 2016). On the one hand, increased electricity imports from the EU would worsen the carbon footprint of Switzerland's electricity consumption mix as they have a higher carbon intensity (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). On the other hand, the rules governing the Swiss electricity market would be made in EU institutions. These include the European Network of Transmission System Operators for Electricity (ENTSO-E), the Agency for the Cooperation of Energy Regulators (ACER), and bodies of the European Commission and Council. Although Switzerland may gain enhanced access to these bodies, its influence would be limited by a lack of formal veto powers (Hofmann et al., forthcoming). These developments would render an independent energy policy impossible, reducing Swiss energy sovereignty.

Summary: At the crossroads of the impossible energy trinity

The foregoing analysis has demonstrated that Swiss energy policy is constrained by an impossible energy trinity of energy security, sustainability, and sovereignty. We have outlined that Switzerland can pursue three main options (see Table 2). In the dirty option, domestic fossil-fuel based electricity generation capacity would be added or the operation of existing nuclear power plants be prolonged to ensure secure supply under a sovereign energy policy. This option would increase CO2 emissions or the amount of nuclear waste. In the insecure option, extensive public subsidies would be used to diversify the domestic renewable generation and build up a strategic reserve. This option would lead to an increase in electricity prices while still entailing some supply risks, both of which could weaken the competitiveness of the Swiss economy. In the non-autonomous option, Switzerland would conclude an electricity agreement with the EU and close its supply gap in winter with electricity imports from the EU. This option would temporarily increase the CO2 intensity of the Swiss electricity consumption mix but ensure long-term sustainability under the assumption that the EU meets its decarbonization targets. Importantly, however, this option would require Switzerland to cede some of its sovereignty by implementing EU electricity legislation.

Table 2: Swiss energy policy options and their trade-offs

Policy option	Energy policy measures	Trade-offs for policy objectives

a. Dirty option	• Add domestic gas-fired electricity generation capacity • Extend operation of existing nuclear power plants • Avoid international energy policy integration	• Increased CO2 emissions from domestic electricity production • Increased amount of nuclear waste, dependent on safety of nuclear power stations
	⇨ Measures compromise *energy sustainability*	
b. Insecure option	• Diversify domestic renewable portfolio by subsidizing less cost-efficient and less accepted renewables • Build up strategic reserve capacity • Avoid international energy policy integration	• High public subsidies and increased electricity prices • Risk of supply shortages and blackouts, costs for grid stabilization measures
	⇨ Measures compromise *energy security*	
c. Non-autonomous option	• Conclude electricity agreement with the EU • Close supply gap in winter with electricity imports from the EU	• Mandatory implementation of EU *energy acquis* • Short-term increase of CO2 intensity of electricity consumption mix
	⇨ Measures compromise *energy sovereignty*	

Compiled by the authors.

At the time of writing, it remains unclear which of these options Switzerland will eventually pursue. The Swiss government remains undecided on whether to endorse a new institutional framework agreement with the EU, which is a precondition for the conclusion of the electricity agreement. Even if the government endorsed the framework agreement, it would remain uncertain whether this would find a majority in a nation-wide referendum. The linkage of electricity matters to broader political questions about the future relationship with the EU undoubtedly further complicates the impossible energy trinity faced by Switzerland. The crossroads at which the country currently finds itself also represents a choice between major policy priorities of Switzerland: 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 strong focus on global competitiveness; and the preservation of sovereignty outside of the EU and EEA. All three priorities have been directly or indirectly confirmed by Swiss voters in previous referenda. Hence, we expect that the impossible energy trinity will soon force Swiss policymakers and voters to make tough policy choices.

Discussion: Management strategies and generalizations

Is there a way that Switzerland can escape the impossible energy trinity? The only feasible way requires the cost-efficient availability and socially accepted use of diverse renewable energy sources (including wind power) and flexibility solutions (e.g., storage via batteries and hydrogen). Because of technological, economic and social barriers to such a cost-efficient domestic balancing of the electricity grid, Switzerland presently cannot escape the impossible energy trinity but only manage it. One management strategy might be to "muddle through" the impossible energy trinity. Switzerland could try to avoid taking any tough policy choices by implementing some 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.

However, it is highly doubtful whether the EU as the larger counterparty would accept an integration of Switzerland into the EU electricity market with significant areas of Swiss energy policy remaining shielded from EU rules.

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 thus adopt a small-but-smart-state strategy (Grøn & Wivel, 2011). Smart influence would build on three elements: an active participation in European energy governance bodies; the continued development of strong technical expertise and its provision in European decision-making processes; and building coalitions with influential EU member states. Switzerland would thereby pursue a secure and sustainable energy system, whose governance it cannot determine independently but shape to some extent.

What can the Swiss case teach us about other countries characterized by energy smallness? Around the globe, the energy transition brings fundamental changes to countries' energy infrastructure and policy. Our conceptualization of an impossible energy trinity explains why small states cannot achieve energy security, sustainability, and sovereignty simultaneously. The Swiss case illustrates the resulting challenges. In Europe, most countries have chosen the non-autonomous option in light of energy smallness vis-à-vis the EU. 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. Cooperation facilitates trade, which renders the operation of the domestic energy grid more efficient. This has had positive effects for security of supply and the expansion of sustainable energy infrastructure (Buschle, 2014). Yet, cooperation requires the adoption of foreign energy legislation which undermines energy sovereignty. Members of the EEA (Norway, Liechtenstein, and Iceland) also adopt EU energy legislation. Nevertheless, based on access to relevant policy-making venues and significant structural resources (oil, natural gas, and pumped storage), Norway has been able to influence the formulation of EU energy and customize its implementation to domestic needs (Hofmann et al., 2019). This case reminds us of the relational element of our definition of energy smallness.

The UK is an interesting case since its departure from the EU following the Brexit referendum is associated with efforts to regain sovereignty. As an EU member, it has been fully integrated in the EU energy market with all consequences for the domestic implementation of supranational energy legislation. Despite its island location, the UK is closely tied to the European energy grid via submarine oil, gas, and electricity interconnectors, the latter of which are being significantly expanded (ofgem, 2020). As a net importer of electricity pursuing an ambitious domestic sustainable energy agenda, including a coal phase-out, the UK's energy security depends on trade through cross-border interconnectors (Ifelebuegu et al., 2017, p. 8 ff.). This raises questions about its aspirations for energy sovereignty. Similar to Switzerland, without a comprehensive energy agreement the UK may face trade-offs in the pursuit of its energy policy objectives (Lockwood et al., 2017). It would then have to compromise on energy security or sustainability for the sake of an independent domestic energy policy. The prospective non-consideration of the UK in key forums of European electricity cooperation (Article 27 of the draft Agreement on the EU-UK partnership) is an early warning sign.

Other countries around the world falling into the category of energy smallness may face a similar fate. In Mongolia, located between the energy giants Russia and China, power produced from domestic coal accounts for more than 90% of the electricity mix. Although the country possesses significant wind and solar potential, the necessary structural changes pose an enormous challenge to decarbonization efforts (Hans et al., 2020). Turning away from the 'dirty option' while ensuring energy security may require increasing integration with the Russian and Chinese electricity systems which might affect energy sovereignty. Developing countries in Asia (Bangladesh, Kazakhstan, Vietnam), Africa (Botswana, countries participating in 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.

In general, countries with easy access to renewable sources may find it easier to manage the impossible energy trinity. In particular hydropower promises deep decarbonization of the electricity mix and storage options for uninterrupted supply. Multiple examples from across the world demonstrate how countries tap their hydroelectric resources in the pursuit of secure and sustainable electricity. However, for some this strategy has proven fallacious. Droughts (Bhutan, Costa Rica, Panama, eastern and southern Africa; cf. Conway et al., 2017), earthquakes (Nepal; Schwanghart et al., 2018), and financial liabilities related to large hydro projects (Paraguay; Schipani, 2019) have called some success stories into question. Research on Ecuador has shown how cross-border trade of electricity from hydropower with the larger neighbor Colombia contributes to secure and sustainable energy supply, but requires increased policy coordination (Ochoa & van Ackere, 2015). An agreement on shared rules could turn out to be a 'non-autonomous option' reducing Ecuador's full control over its energy policy. Overall, these examples suggest that rather than escaping energy smallness through self-sufficiency, hydropower can reinforce dependencies on neighboring countries, visualizing the impossible energy trinity for small states.

Conclusion

In this article, we argued that small states face an impossible energy trinity where they cannot pursue energy security, sustainability, and sovereignty simultaneously. Our point of departure was a relational definition of energy smallness. The relevant dimensions are the availability of diverse and cost-efficient renewable energy sources, possibilities for balancing the electricity grid, access to trading platforms, and marketing opportunities supporting the attractiveness of renewable investments. A state is small in terms of energy when, across these dimensions, it is more dependent on another state or market than vice versa. Small states have to make tough choices in their energy policy strategies. First, they can pursue a dirty option, in which they sacrifice sustainability for the benefit of energy security and sovereignty. Second, they can choose the insecure option in which sustainability and sovereignty are achieved at the expense of energy security. Security here broadly refers to the accessibility, availability, affordability, and acceptability aspects of energy. Third, they can select the non-autonomous option which achieves secure and sustainable energy by giving up sovereignty through the integration with a larger market. We empirically illustrated these options using the case of Switzerland. The country currently is an energy policy island surrounded by the EU. The strong physical interconnection between the Swiss and EU electricity systems provides a large potential for balancing the Swiss grid also under increasing intermittency from renewable electricity production. At the same time, this strong interconnection reinforces the impossible energy trinity the country is confronted with. The case study demonstrated that Switzerland currently finds itself at the crossroads of selecting one of the three policy options.

Our article does not offer any easy prescriptions on which strategy a small state should choose. Yet, 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: On the one hand, increasing public pressure for the decarbonization of the economy makes the dirty option unlikely, especially where countries already have electricity mixes with a low carbon intensity. On the other hand, energy security continues to be essential for the economic competitiveness of small open economies. The importance of secure electricity is set to increase in an ever more electrified and digitized society. By contrast, we see potential for ceding energy sovereignty when accompanied by greater possibilities for shaping the formulation of policies of the entity to which decision-making powers are transferred. The small-but-smart-state strategy seems to 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 of the idea that a small state should transfer control over parts of its energy policy to another state or group of states. One argument that could proof useful in this respect is to consider the structural power that might result from a greater interconnection with larger states and from their increasing dependence on energy infrastructures in smaller states. Switzerland with its central position for electricity transits that are critical for further EU electricity market integration is once again an instructive example for this (Hofmann et al., forthcoming).

These findings and conclusions speak to literature on the political economy of renewables, network interdependencies, and small states in the energy transition. Regarding the politico-economic dimension of renewables, we note that a transition to cleaner sources for electricity generation may increase demand for the regional integration of electricity grids. Cross-border electricity interconnectors call for governance systems for the operation of joint networks and markets (Ringler et al., 2017), which may entail geopolitical implications (Fischhendler et al., 2016). Our model echoes research into network interdependencies by considering that control over critical energy network infrastructure determines the power relationship between countries involved in these governance efforts (Farrell & Newman, 2019; Thaler, forthcoming). Especially, we showed that energy smallness resulting from a lack of network control forces countries to make tough choices between energy security, sustainability, and sovereignty. Smallness in international electricity relations thus limits the options available in domestic energy policy. We encourage future research to explore how countries other than Switzerland are coping with this situation.

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