Final Report

Energy security in scenarios for Europe's future electricity supply

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About this paper

In the last few years, a number of studies concerning pathways for the very far-reaching decarbonisation of the European power system were published. These studies have had a considerable impact on both climate and energy policy and on the European energy debate in general, because they all conclude that it is *technically possible* and probably even *economically beneficial* to decarbonise the European power sector by 80-100% by 2050 using mainly, or exclusively, electricity from renewable sources in a pan-European, Supergrid, approach, supported by electricity imports from the Middle East and North Africa (MENA). Most of these studies also reach the conclusion that decarbonisation through renewables expansion is *secure*: that it can maintain or increase European energy security compared to today (e.g. Dii, 2012; DLR, 2006; ECF, 2010; Fischedick et al., 2012; SRU, 2010).

The last statement is important, because energy security is a high priority for policy makers. At the same time, there is reason to be worried that the empirical and analytic basis for the security statement is less robust than the statements concerning technical and economic feasibility. In many energy and electricity scenarios, Europe will import a substantial share of it its energy needs, either in the form of fossil or nuclear power plant fuels or, as is the case in Supergrid decarbonisation scenarios, as renewable electricity. However, it is not always clear from which regions or countries these imports originate, or in which setting they will take place. In most cases, "energy security" is not even defined, and it lies at hand that the subject of the security considerations may vary widely across different studies. Generally speaking, the energy security statements in the Supergrid studies are often weakly underpinned or, in some cases, it is not at all clear what the base for such a strong conclusion is. Still, any scenario of the future electricity supply must prove that it is secure, or Europe would be well advised not to pursue policies that support developments in the direction pointed out in the scenario. Finding out whether importing renewable electricity from MENA would be a threat to European energy security was the aim of the project, the results and implications of which are summarised here, together with an overall conclusion.

The project was carried out in three parts, all based on novel theoretical, epistemological and methodological approaches, which are described in detail in a series of scientific articles. First, we clarified the concept of energy security from a European policy-perspective, identifying the core components of the concept as they are relevant here (see Lilliestam and Patt, 2012, Lilliestam et al., in review-a). In the second part we explored the political risks, here narrowed down to the frequently discussed issues of dependence and "energy weapon" events on the one hand (see Lilliestam and Ellenbeck, 2011, 2012) and terrorism attacks on the other (see Lilliestam, in review). In the third part we assessed the overall failure risks of electricity scenarios (see Lilliestam et al., in review-b). We describe each of these research tasks and results in section 1 – 3 of this document, and then in section 4 evaluate, holistically, overall energy security of renewable electricity imports for Europe.

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Table of Contents

1 What is energy security?

Some issues in the energy debate are clear, at least concerning what they are about. For example, it is clear that a climate protection discourse is about greenhouse gas emission reductions: how far and how fast emission reductions need to take place and by which means this can best be achieved are the main areas of debate. By contrast, it is less clear exactly what the subject in the energy security discourse is, although the term energy security is widely used in both policy and academia.

Several recently published articles have risen to the challenge to shed light on what energy security is, and to broaden what they refer to as the obsolete "mainstream" paradigm of energy security research centred on the vulnerability to oil import shocks. The result of this new research stream is a "new comprehensive energy security paradigm", with definitions of up to 20 separate dimensions, consisting of up to a staggering 372 issues, all of which should be assessed quantitatively. Thus, presently the definitions of energy security range from "old" and very narrow ones – e.g. the "likelihood that energy will be supplied without disruptions" (IEA, 2002:9) – to "new" and extremely broad ones – e.g. "the challenge of equitably providing affordable, reliable, efficient, environmentally benign, properly governed and socially acceptable energy services" (Sovacool and Rafey, 2011:93).

The European Commission states that energy security means "ensuring, for the well-being of its citizens and the proper functioning of the economy, the uninterrupted physical availability of energy products on the market, at a price which is affordable for all consumers (private and industrial), while respecting environmental concerns and looking towards sustainable development" (EC, 2000:2). This is similar to the broadest of academic definitions, but it is extremely inclusive, raising questions about what is left for the two other energy policy goals of "competitiveness" and "sustainability" when these are claimed for the domain of energy security. In a way, it security – as in energy security – may have evolved into a term that represents all that is good, making it similar to other terms like justice or sustainability, which are also positively laden but largely devoid of concrete meaning. This also raises questions about how this deeply political concept is used by policy-makers: whether they really address this many things simultaneously, or if energy security is also a rhetorical figure used to justify other policies.

Therefore, we developed a new approach to defining energy security (described in detail in Lilliestam and Patt, 2012; Lilliestam *et al.*, in review-a). Instead of normatively prescribing what policy makers *should* worry about, we sought to analyse what they actually *do* worry about while implementing actual energy security policy. By focusing on the concrete measures of energy security policy, rather than the rhetoric, we found it possible to filter out secondary concerns and arguments that are merely rhetoric, allowing a more productive focus on the core concerns of energy security in a particular context: concrete policy measures must concentrate on the most pressing issues, as they cannot afford to focus on factors of secondary importance.

We applied the new methodological framework to the energy security policy of the European Commission (EU), and flanked this by the two cases United Kingdom (UK) and Sweden (SE). The two country-cases where chosen with due respect to variance in energy system and governance structure[1], to provide rich material for both highlighting the context-dependency

[1] For example, Sweden, which has a very high electricity demand and an strong reliance on renewables and nuclear power, faces other challenges and can be expected to perceive energy security differently than the UK, whose energy system is more characterised by reliance on dwindling domestic fossil resources.

of energy security and for finding some generalisable principles, or at least principles that can be generalised across Europe.

In total, we identified and analysed over 70 different policy measures. The results show that energy security is indeed multifaceted, but it is a much more narrow concept than often described in recent research. It is also more narrow than suggested by policy rhetoric itself, indicating that the term of energy security, while being a policy concept of its own, is an important tool for policy-makers to justify policies in various parts of the energy system.

It was found that European energy security as perceived and operationalised by policy does not pay attention to all energy carriers at all levels: instead, it is concerned with electricity and gas end-use and supply at mainly the national and regional levels. Oil supply and its primary end-use, transport, were mentioned in the EU and UK cases, in the form of policies for more efficient vehicles and new transport modes, but these sectors are far from being a focal point of these energy security policies. Other energy carriers and sectors, such as coal and nuclear power, are discussed as subsets of electricity supply, without concerns regarding their security. In the three cases, observed energy security policy measures address at least one of 8 threats to energy security, see Table 1.

Table 1: Threats addressed by energy security policy measures.

Geopolitical threats	Roughly foreseeable threats	Unpredictable threats
Refused access to foreign resources (EU, UK)	Reliability issues, infrastructure failure (e.g. underinvestment, asset aging)	Terrorism (EU, UK)
Intentional cut-offs, "energy weapon" (EU, UK)	Infrastructure failure (e.g. natural extreme events)	Strikes, unrest (UK, EU), war (Sweden)
	Resource depletion, concentration of remaining resources (EU. UK)	Unprecedented natural events

Energy security policies address risks of both physical and economic nature. Concerning the latter, the threat actually addressed by policy is volatile or "uncompetitive" prices, as the results of distorted or badly functioning markets, which cause economic damage in especially industry, and increases investment risks in the energy sector – and this, in turn, increases the risks of underinvestment and technical breakdown due to aging infrastructure.

In addition, we identified a number of issues that are used in energy security rhetoric, but are not reflected in actual policy. First, energy security policy rhetoric often refers to "affordable" ("acceptable", "reasonable", etc.) energy prices. At a first glance this is similar to the academic discussion of "affordability" of energy as a dimension of energy security. However, a closer look shows that the interpretation of "affordability" in energy security policies is often exactly the opposite of "low" prices and does not take energy poverty into account: some actual energy security policy measures (e.g. the introduction of new technologies) indirectly and, perhaps, involuntarily increase prices, at least in the short-term, whereas other measures (e.g. energy taxes) indeed aim to increase rather than decrease energy prices. Thus, definitions of energy security as "uninterrupted physical availability of energy products on the market, at a price which is affordable for all customers" (EC, 2000:2) or similar sometimes presented in the policy documents turn out to be mainly rhetorical figures.

Second, environmental considerations could also not be identified as a component of energy security. Specific energy security policy measures do however interact with climate change policies, since they affect the same energy systems. We observed two main types of such interactions: First, the planned energy system decarbonisation forms a constraint to the design of energy security policy. This constraint, for example, prevents using domestic coal without CCS as an energy security solution. Second, some energy security and climate change measures are perceived as identical or synergistic, such as the development of domestic renewable resources, expanding/maintaining the nuclear capacity, or increasing energy efficiency. These overlaps present ample opportunities for political manoeuvring, and make it politically expedient to package these measures together using the rhetoric of multiple benefits of "sustainable and secure" energy (EC, 2008:17). This rhetorical fluidity and thematic overlap can be observed in all three cases; especially the UK and the EU frequently refer to the climate benefits of energy security measures, or vice versa. This fluidity is highlighted by a number of examples: for example, the energy policy in the UK in the 2000s has shifted from being primarily justified on climate change grounds to being primarily justified on energy security grounds, although most measures, prominently nuclear power expansion plans, remained conceptually identical. Equally, the Swedish policy of completely phasing out oil from the energy system by 2030 is not once discussed as an energy security measure by the policy documents: this program, which doubtlessly will have a strong impact on Swedish energy security, is viewed solely as a climate policy measure.

Overall, at least in the three cases that we considered, we have shown that energy security is not a very complex issue, but rather one that consists of only few "dimensions" addressing only a small number of threats to electricity and gas. This has some implications for research, as it indicates that many potential threats, especially higher prices and environmental issues, are only secondary concerns for actual energy security policy-making. It also has implications for understanding the current European energy policy, by highlighting the fact that there is a discrepancy between energy security policy rhetoric and actual energy security policy: although energy security is a policy and research field of its own, the term "energy security" is frequently also used to justify policies that are in fact not energy security policies.

2 How severe are the political risks of renewable electricity imports to energy security?

The political risks of renewable electricity imports are often the ones that are meant when talking about energy security and Supergrid scenarios. These risks resonate well with both the policy community and the wider media landscape: the mental picture of an Arab terrorist attacking the power supply of Europe is easy for media to produce and for the readers to understand; the geopolitical threat of an unreliable exporter country cutting energy deliveries to Europe is equally easy to understand, also based on parallels to the 1973 oil crisis and the Russian-Ukrainian gas disputes, and is an issue that traditionally concerns the classical political security elite. That said, it is not so easy to actually, robustly, assess these risks. In the present project, this was done in two blocks, separately looking into the risks of "energy weapon" events and dependence, and of terrorist attacks.

2.1 Energy weapon events and dependence

The thought of Europe importing renewable electricity from the MENA frequently triggers unpleasant parallels to the European dependence on Russian gas and OPEC oil. Such "energy weapon" action, in which the exporters have suspended (or threatened to suspend) exports as a tool to put the importing countries under pressure and force them to accept political or economic demands, have been seen, with severe impacts in Europe and elsewhere. Prominent examples of such events are the 1973 oil crisis, and the 2009 Russian-Ukrainian gas crisis. If by importing renewable electricity Europe exposes itself to another energy crisis, this time around with Supergrid electricity, it may be worth considering another development for the future.

During the run-up for and beginning of the project, we carried out an in-depth analysis of these dependence risks for the Supergrid scenario Desertec, which foresees imports of 17% of Europe's electricity needs from the MENA in 2050 (the methods, data and results are described in detail in Lilliestam and Ellenbeck, 2011, 2012). Our thinking on this topic is rooted in the concept of interdependence: Europe will, should it import significant amounts of renewable electricity, to some extent be dependent on the stable supply from the exporter states. Given the importance of electricity for modern economies, blackouts or unreliable supply can be economically devastating. On the other hand, the exporters will also be dependent on Europe: the income generated from the electricity exports will be an important contribution to the national (or government's) revenues. Thus, focusing only on the importer's dependence removes the context of the issue, which is problematic as import dependence is not a dangerous thing *per se*. Instead, the interesting question concerns the symmetry of the importer's and exporter's dependence on each other: if one side depends more on the trade than the other, then the less dependent side can potentially use the trade as a source of bargaining power. If Europe depends more on the electricity trade than the exporters do, Europe could be exposed to dependence risks.

The results show that the risks are small, for two main reasons:

- First, Europe is likely to be able to restore system operations following all but the most extreme disruptions, as the magnitude of the imports from a given country is too low to exceed Europe's response capacities (mainly control and spare capacities, as well as demand reductions). In all cases where only one country disrupts exports, the blackouts are limited geographically and the system is likely to be reignited within hours; the impacts on the European economy are locally significant, but temporally highly limited.
- The second reason is closely related: following an export cut, Europe first faces high blackout costs, but after a few hours the costs are minimal (caused by the slightly higher costs of reserve generation). The exporter, on the other hand, faces constant costs, originating in lost income, at a higher level than the European reserve generation costs, until the exports are resumed. As a consequence, the exporter has no leverage: Europe can simply wait the exporter out.

However, the impact of an event where all exporters join in cutting supplies to Europe would be devastating, causing wide-spread blackouts which are unlikely to be remedied by European responses alone. In this case, Europe would indeed be vulnerable and asymmetrically dependent on the exporter states, and it could be attractive for to take measures to minimise this small, but non-negligible, vulnerability. And even if the risks of a one-country disruption are small, Europe may want to further reduce its potential vulnerability.

The interdependence approach leads to a number of cornerstones for possible strategies to minimise the European geopolitical risks in a Supergrid future. The key to this lies in managing and fostering the interdependence between Europe and the exporters, including strategies affecting both the impacts of an extortion event, should it occur, and the probability that it happens by reducing the attractiveness for the exporters to wield the energy weapon. Three main priorities stand out:

First, diversifying the countries of origin reduces the potential leverage of each single supplier. Taking this argument seriously implies that production sites for renewable electricity exports should not be chosen exclusively based on costs and the quality of the solar or wind resources, but should also acknowledge the value of spreading the production across many countries. This means that it would be beneficial for Europe to seal electricity trade deals with as many countries as possible, and possibly limit each country's share, in order to avoid a dash for electricity from a single country with particularly good resources.

Second, increasing the emergency response capability on the European side further reduces the leverage of the exporters, as the impacts of a potential export cut are reduced. This does not necessarily, or at least not exclusively, mean increased control or spare capacities, which would be expensive due to its (hopefully!) low utilisation. It also means increased demand-response capabilities and, in particular, the improved integration of the national power systems and markets, in order to spread the risks and enable a common European emergency response which is stronger than the response of single countries alone.

Third, increasing the exporters' dependence on the trade will reduce the attractiveness of a politically motivated export cut as it raises the stakes on the exporter side. This would in particular require the exporting countries themselves to invest in the power stations generating the renewable electricity and the export transmission lines. These assets have very high capital costs, and hence they depend on constant trade to be economical. If the exporters have made these sunk investments, cutting the exports will be all the more costly to them, and the incentives for a politically motivated disruption are lower. Increasing local support and buy-in for electricity exports would require factors like local manufacturing of components in North Africa to be emphasised stronger, and the hiring of local people to work at the power stations to be actively encouraged. This, on the other hand, could make the Supergrid system less attractive to Europe, as it would pay for the electricity but a large share of the profits of the electricity trade, as well as a number of macro-economic advantages, would benefit North Africa instead of Europe.

The third point also highlights the hotly emphasised issue of ensuring that the exporters have sufficient generation capacity for their own needs before electricity is exported to Europe: if, for whatever reason, the exporters have insufficient capacity, they have a very strong incentive to disrupt electricity exports in order to satisfy their own needs. Hence, ensuring North African electricity sufficiency first is not only a moral issue of avoiding new neo-colonial energy schemes, but it may prove to be vital also from a Eurocentric security perspective.

In addition, two further points are often overlooked, perhaps because they are soft factors, or perhaps because they are not solely limited to the domain of energy policy. First, good relations between Europe and North Africa will be of crucial importance. This is, of course, a trivial observation, but it is true and often forgotten in the discussion. Friendly relations both reduce the probability for hostile events to happen and increase the disincentives of an exporter to extort a partner.

Second, the institutional setting greatly affects the possibilities to use the electricity trade as a political tool; institutional integration between Europe and North Africa may thus prove to be a valuable way to manage the political risks, and change the perception of these. So far, much of the Supergrid discussion has viewed the exports as bulk transfer of dedicated export electricity, distinct from the general electricity supply framework. This is a main source for the worries about political extortion risks: bulk point-to-point transfer is easy to understand, and lends itself very well to power considerations and analogies to pipeline gas import vulnerabilities. If, however, the electricity is allowed to flow freely in a meshed system on an open European-North African market with common rules and institutions, the situation is completely different: it would be physically much more difficult (or impossible) to cut supply to a particular country, and the legal and practical possibilities of exporter governments to access energy trade as a forceful foreign policy instrument are reduced.

Thus, the dependence and "energy weapon" risk of renewable electricity imports are low, and there the effective implementation of a few simple concepts could further reduce the remaining risk. Instead of the intuitive answer to minimise European import dependence in order to increase its energy security, a powerful overarching strategy to reduce European energy security risks in a renewable Supergrid electricity future may consist of a combination of preparing for emergencies and of targeted measures to foster and deepen the dependence of both sides on each other.

2.2 Terrorist attacks

Whereas importing significant amounts of electricity from any country raises concerns about dependence, importing electricity specifically from the Arab countries in the Middle East and North Africa also trigger European fears of terrorist attacks against the import infrastructure. This fear appears to be rooted in a general feeling of threat and European popular suspicion against the Islamist organisations, in particular Al Qaida, present in many MENA countries, and is underpinned by the prevailing understanding of terrorists' target selection. Generally speaking, terrorist targets are high-profile targets, with the aim to create fear – or *terror* – in an enemy audience wider than the population immediately affected by the attack. Thus, attacks are typically carried out to fulfil at least one of five attributes: (1) to cause large human casualties, (2) to destroy physical facilities, (3) to inflict great economic damage, (4) to disrupt the functioning of the government, (5) or to destroy a symbol of the culture/country the terrorists detest. At least points 2-4 could apply for critical energy infrastructure (CEI), and in particular to electricity infrastructure, making CEI a potentially attractive target.

However, terrorist attacks against energy infrastructure are very rare in MENA (outside Iraq), and energy infrastructure attacks affecting supply in a mentionable manner are extremely rare in MENA and have never happened in Europe. Recently published research explains this low attack frequency by the indiscriminate effects of energy outages, affecting supporters and enemies alike, and by the low political symbolism attached to energy targets (see Smith Stegen et al., 2012; Toft et al., 2010). Furthermore, an explaining factor could be the low fear-creation potential of terrorist attacks: unless the induced outages are spectacularly large and long-lasting, they are costly and annoying, but they are unlikely to cause wide-spread fear in the target population – and causing fear is typically the main aim of terrorist attack.

Whether this argumentation holds for the future is unclear. It cannot be ruled out that future terrorist groups attach strong symbolism to energy infrastructure: terrorist groups such as Al Qaida already see energy installations as attractive targets, supporting both the "crusader nation" (the US) and the MENA governments cooperating with it. Further, the effects of cutting supply in point-to-point electricity links or gas pipelines are not necessarily indiscriminate: it would primarily affect the exporter (lost income) and the importer (lost energy), but not necessarily the general population in the exporter country. And, importantly, it is correct that historical blackouts in Europe have not caused wide-spread fear. On the other hand, spectacular CEI attacks have not happened in Europe, nor has Europe experienced large and sustained (greater than a day or so) blackouts, so the data underlying the no-fear argument is hardly valid.

As a consequence, one cannot know that CEI attacks will remain unattractive (and thus infrequent) and of low impact. Instead, one can assume that if a future energy supply pathway holds inherent vulnerabilities, the impacts of terrorist attacks may be significant, and the terrorist threat may become significant. A very large-scale attack is *possible* (with no statement about probability), and a spectacular, long-lived terrorist-caused outage *could* fulfil both the fear-creation and the high-impact criteria, making the potential effects of a large-scale terrorist attack a prime determinant for the terrorism risks of a scenario. Hence, we focus on various ways to estimate the potential impact, as a proxy both for European vulnerability and attractiveness for terrorists to attack CEI supplying Europe (the methods, data and results of the terrorism risk assessment are described in Lilliestam, in review).

In this, it is important to acknowledge that if Europe opts out of one possible pathway, it must choose another one, and this alternative pathway will come with its own set of vulnerabilities. There is no null-option. We therefore assessed and compared the vulnerability of two distinct decarbonisation scenarios: a Supergrid scenario with renewable electricity imports (Desertec) and a scenario depending on gas imports and gas power coupled with CCS for its electricity generation (from the Global Energy Assessment).

The results show that the inherent terrorist attack vulnerabilities of the import systems for electricity and gas are low, as the systems are both diversified and have considerable buffers. Traditional, forceful attacks are highly unlikely to cause spectacular (i.e. very large and long-lasting) outages and cause severe economic damage, as system functionality can be restored in most attack scenarios. It is already difficult to overcome the buffers and cause an outage at all: the buffers require terrorists to simultaneously disable at least 2 or 3 power lines if the aim is to cause a blackout, whereas between 5 (extremely conservative case) and over 100 gas import points must be disabled to overcome the immediate gas buffers. If the aim is to cause spectacular impacts which cannot be quickly remedied, a much larger number of simultaneous, successful attacks are required: this would likely require terrorists to disable all import links, both for gas and electricity – forcing them to carry out between 30 and 120 simultaneous attacks across a huge area. This is a very difficult task for a national army, and almost impossible for a terrorist group.

Therefore, this could make such attacks unattractive to terrorists, especially when compared to attacking other targets, in particular human targets, with higher fear-creation and economic damage potential, so that a group capable of carrying out many simultaneous attacks may choose another target than the energy system. Possibly, a cyber-attack disabling the control systems is the only way short of a war to cause simultaneous failures at sufficient scale to cause really devastating outages. Although this is a purely speculative possibility, it cannot be ruled out: if they find a way to carry it out, a cyber-attack, either against the power or the gas supply systems, may be attractive to terrorists due to its potentially spectacular impacts; this would however not be a risk specific to an electricity import scenario, but be a risk shared among most potential electricity futures.

Although both scenarios show low vulnerabilities, electricity imports are clearly more vulnerable than gas imports. This conclusion is robust, as it originates in the different physical characteristics and the design of electricity and gas supply systems, and these will not change dramatically (e.g. electricity will be traded through power lines of some, roughly knowable, size; gas will be imported through some combination of LNG and pipelines, etc.). The most important difference is that gas can be stored in meaningful amounts, whereas electricity cannot. Consequently, an electricity system must be balanced at every instant, and is designed to withstand the failure of one unit (n-1 principle), but not necessarily two: even a short mismatch can trigger blackouts. The gas system is not designed to support peak demand with supply, but relies on storages during the rare (up to 30 days in 20 years) peak demand times. Thus, there are generally large gas storage-draw capacities available to buffer disturbances: during average demand times, all attacks short of disabling all chokepoints are unlikely to cause shortages. As disturbances are buffered and propagate slower through a gas system, it has a lower vulnerability to import chokepoint failures than an electricity system.

Therefore, European energy security is not particularly vulnerable to terrorist attacks, regardless of whether it chooses the renewable electricity import pathway or opts for gas imports and CCS. The main reason is that the impacts of even successful attacks are likely to be limited. This already reduces the threat to Europe (as outages are manageable), but it also reduces the attractiveness of such attacks to terrorists, which in turn reduces the likelihood of such events happening. This threat can be further mitigated, by ensuring first of all that the import routes are not bundled into the same narrow corridors: reducing the size of the import routes increases the number of attacks needed to overcome the European buffers, which makes a successful and spectacular attack more difficult and less attractive. In addition, it is important that Europe maintains its buffers and spare capacities at least at the level foreseen in the assessed scenarios. For this, a prerequisite is that the European electricity (or gas) system is integrated, so that a disturbance in one country can be mitigated by the full capacity of the combined European response capacities and re-routing of spare capacity to the affected region: expanding and unifying the gas and electricity transmission grids is not only a market measure, or one to better integrate renewable power, but it is also an important measure to ensure European security of supply.

3 Probabilistic assessment of energy security

In the previous steps of the project, we answered the question of what energy security is about, and investigated the political risk component of a Supergrid renewable electricity import scenario. However, political risks are not the only risks present, even if they are the most frequently discussed. Therefore, we also carried out an overall assessment, including natural (intermittency), technical (the risk of component breakdown, due to random factors and natural extreme events) and political risks into one direct measurement.

The question is an old one of whether a particular pathway is secure, and it is frequently assessed in the academic and policy literature. Consequently, there are many methodologies to assess energy security. Most of these use indicators, either in an array consisting of numerous indicators or aggregated into a one-point index. Such measurements, while being interesting and useful in many respects, have especially two serious shortcoming: the indicators are proxies, only remotely measuring a subset of energy security, and a one-point index must, per definition, be on an ordinal scale. Therefore, such assessments can only make statements about whether a scenario is more or less secure than another, but they cannot answer the questions about *how much* more (or less) secure the scenario is, and – importantly – they cannot answer the question whether a scenario is sufficiently secure.

Therefore, in this part of the project we adopted a view on energy security as the probability that electricity will be supplied without interruption (the methods and results of this are described in detail in Lilliestam *et al.*, in review-b). We constructed a model in which electricity or gas (for electricity generation) is imported to Europe through a number of separate energy streams, one for each source and country (i.e. one wind power and one solar power stream from Morocco, one gas stream from Russia, and so on). Each stream was assigned a capacity, which was taken from the scenarios assessed, and a failure probability, composed of the three risk components natural, technical and political risk:

- The natural risk depicts the availability of intermittent wind or solar electricity generation;
- the technical risk depicts the risk that an import line, a power plant or a gas well breaks down, or is shut down for maintenance; and
- the political risk depicts the risk than an exporting or transit country will stop deliveries to Europe.

The risks were quantified using historical weather data for natural risks, historical failure and maintenance rates for the technical equipment, and by using country risk insurance rates as a proxy for political risks. The model was implemented for two scenarios: Desertec, and the European Commission's gas-dependent business-as-usual (BAU) scenario. These scenarios were compared to the situation in today's European power system.

The results show that both scenarios examined are less secure than the current situation, although the difference between Today and BAU is not significant. They also show that the renewables-based Desertec scenario is probably less secure than a gas-dependent BAU scenario. The higher Desertec risks are mainly caused by the variability of domestic renewable generation, and to a lesser extent by political risks of importing electricity from North Africa. In fact, the political risks are higher in the gas-import dependent BAU scenario and Today than in the Desertec scenario, largely due to the lower overall import dependency in Desertec. The slightly higher risks in the BAU scenario compared to Today originate in higher shares of domestic intermittent renewables and the higher dependency on Russian gas.

Thus, two important conclusions can be drawn. First, increasing dependence on imports increases the overall supply risks, but the even the massive increase in the BAU scenario does not generate significant differences compared to today's situation. Second, the risks of a Supergrid-style decarbonisation are higher than in the other scenarios. Importantly, however, the main risks lie not in foreign countries and their supposed unreliability, but in the volatility of domestic renewables. Thus, this is not a Supergrid-specific risk, but one inherent in all scenarios based on renewables, imports or not. Finding ways to reduce and handle the volatility or renewables, for example by reinforcing the transmission network, or by accessing more flexible, dispatchable generation is key to ensuring the energy security of a renewables-based electricity system. Opening up for imports of dispatchable solar power from outside Europe may slightly increase the political risks, but it allows for a potent option to mitigate the risk source overshadowing all other – the intermittency risk.

4 Conclusion: Are renewable electricity imports a threat to European energy security?

The project "Energy security in scenarios for Europe's future electricity supply" has generated a number of new insights, both concerning energy security and the associated discourse, and concerning the risks of decarbonising the European electricity system partly based on renewable electricity imports. In addition, a number of new epistemological and methodological approaches and insights have been generated, as described and discussed in detail in the articles produced during the work.

Energy security is a fairly narrow concept at the core, when it comes to actual action in European policy, and a very broad concept when used in energy policy rhetoric. In its core, energy security is mainly about the physical availability of energy, the reliable distribution of sufficient energy to consumers, and about the undistorted functioning of markets. When reference is made to concepts like energy poverty and affordability of energy, or to environmental aspects, the concept of energy security is used rather as a rhetorical figure, or as support to justify some political decision, than actually referring to energy security in a stricter sense.

Using the narrower concept of energy security, this project has shown that the political energy security risks, consisting of geopolitical and terrorism risks, of importing renewable electricity are small, and manageable. Three particular points stand out:

- The risks of dependence and "energy weapon" events are small, as the exporters are unlikely to be able to produce a credible threat and a strong leverage over Europe, and therefore they are unlikely to be able to force Europe into accepting political or economic demands. In addition, the small remaining risk can be mitigated if the interdependence between Europe and the exporter states is deepened, especially through institutional and market integration, if the European supply structure is diversified, and if the stakes for the exporters are increased by emphasising the value-creation in the exporting countries.
- The risks of terrorist attacks against the electricity import lines are small, as the impacts of all but extremely well-coordinated and numerous simultaneous attacks are likely to be limited. Thus, such attacks are very difficult, and thus unattractive, to carry out. The limited impact of even successful attacks further reduces the attractiveness of energy infrastructure as a terrorist target. Maintaining sufficient buffers and integrating the European markets and systems are, together with limiting the size of each individual import link, the most important measures to minimise the terrorism risks.
- The largest risk to European energy security is not the political risks, despite their prominence in the public debate. Instead, the volatility of wind power and PV generation is the by far largest source of risk for interruptions in supply to the final consumers, and these are so large that the energy security risks of a Supergrid scenario are probably somewhat higher than of a gas-based business-as-usual scenario – not because of the import risks, but because of the high shares of domestic fluctuating renewables.

Thus, the principal goal for European energy security policy should be to ensure that the grids are reinforced so as to minimise the fluctuations in the overall system, and to ensure that sufficient flexibility options, in particular dispatchable supply, are present. The idea of solar power imports from the desert fills exactly this function by adding another dispatchable option to the renewables-based European power system. In conclusion, importing dispatchable solar power may slightly increase the political risks, but it may strongly reduce the much more important intermittency risks of domestic renewables. Therefore, importing renewable electricity would probably be not a serious threat to European energy security, but it could be an important tool to improve it.

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