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Renewable energy, energy security and resilient societies

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Abstract

Sometimes energy security is used as an advocacy for renewable energy systems. Although renewable energy systems can surely have such characteristics they will not per se solve all types of security problems, and new problems will most certainly arise. In this paper, energy security aspects of renewable energy systems are analysed taking the starting point in a broad typology on energy security. Various renewable energy systems will be discussed from an EU perspective, however noticing the on-going development of global renewable energy markets. Three specific areas will be discussed more thoroughly: the expansion of biofuels, the integration of large quantities of variable electricity in the electricity system, and the existing plans for providing significant parts of renewable electricity from Northern Africa. Furthermore, the importance of various institutions is touched upon.

Keywords

[Renewable energy, energy security, energy markets, biofuels, solar energy]

1. Introduction

The global energy system is dominated by fossil fuels. Renewable energy (RE) contributes with around 13% to total global primary energy supply (IEA, 2010) but the fraction is growing. In the EU, RE contributes with around 10% to total energy (European Commission, 2011a), but the importance of RE varies significantly among countries. Whereas in Sweden and Finland, RE contributes around 40 and 30% of total energy, respectively, in other countries such as the UK or the Netherlands only a few percent of total energy is supplied by renewable energy (European Union, 2009a). The difference is a result of variation in geographical conditions as well as in political priorities.

The energy policy of EU stands on three pillars: competitiveness, security of supply and sustainability (European Commission, 2010). Although the expansion of RE is motivated primarily by its potential to reduce climate change, its importance for the other pillars of EU energy policy is also frequently highlighted. As a part of EU energy and climate policy, a RE directive (European Union, 2009a) was decided, requiring the member states to contribute to a doubling of RE from 2005 to 2020 up to 20% of total energy. In the longer term, this fraction could increase even more (European Commission, 2011b).

RE in EU is currently dominated by biomass and hydro power. During recent decades there has also been a rapid expansion of both wind power and solar energy, although from relatively low levels. Since the year 2000 the use of biomass-based transportation fuels (biofuels) has also undergone a significant expansion and biofuels' share in transport was in 2008 approximately 3.5% (European Commission, 2011a).

A significantly larger fraction of renewable energy in the European energy system will affect various energy security aspects. To evaluate the consequences it is important to clarify the meaning of energy security. Often focus has been on energy dependency but the existence of a causal link between energy dependence and insecurity can be challenged. There are many reasons to believe that energy independence with regard to RE is neither achievable nor desirable as many countries lack the geographical conditions to produce sufficient amounts renewable energy in environmentally or economically viable ways.

Furthermore, the expansion of variable energy production will require a palette of technologies and institutions to safeguard security of supply, for example complementary flexible generation, improved forecasting, electricity demand response, system operation and planning tools, storage and investments in transmission and distribution infrastructure (Sims et al., 2011).

In this paper we will discuss various energy security implications of an expected large-scale expansion of renewable energy. The discussion will concentrate on bioenergy, hydro power, wind power and solar energy (thermal and PV), which are often regarded as the most important RE alternatives for the future.

2. Various perspectives on the relation between energy and security

In the research literature a variety of definitions and approaches to energy security exists depending on scope and scientific background. An effort to describe the variety of perspectives

has been made by Johansson (2011) who identifies two principally different approaches to energy and security, Fig. 1. Within the first approach, focus lies on securing the functionality of the energy system enabling it to provide the energy services demanded in society without major interruptions or price disturbances (see e.g. Grubb et al., 2006; IEA, 2007). These aspects are usually included in the term security of supply (SoS). Within this first approach, one could also choose to take the perspective of the energy supplier for which “Security of demand” is essential for preserving stable incomes etc (cf. Harks, 2010). Integrating the perspectives of the consumer and supplier could be motivated by their mutual but different interests in a well functioning energy system (see e.g. Bressand, 2010).

Within the second approach, focus instead lies on security threats to society that is generated or exacerbated by the energy system, Fig. 1. Such threats could for example emanate from the economic value of the energy resources that sometimes lead to conflicts between states, internal conflicts, civil wars, crime etc. Both scarcity of energy resources and overly abundant resources (cf. Humphreys; 2005) could be generators of conflict. For the latter, the concept resource curse is often used. Other threats could be related to malfunctioning technologies such as nuclear accidents, oil leakages etc (see e.g. Hirschberg et al., 2004) or the security consequences of climate change emanating from expected releases of greenhouse gas emissions (cf. Mobjörk et al., 2010).

Although the typology of energy and security presented in Fig. 1 could be helpful when analysing the security aspects of energy it should be noted that it is not possible to create a firm delimitation to other policy arenas such as environmental policy and economic policy. For example, energy’s impact on the climate is, with good reason, usually framed as an environmental or a development issue (Johansson, 2010).

There are both unintentional and deliberate threats to SoS and the type of countermeasures will vary among threats. The threats can develop to disturbances such as blackouts and other supply interruptions, short-term price fluctuations and long-term price changes due to resource scarcities etc. All these types of threats could have a negative impact on both social and economic development. Whether all these impacts on social and economic development should be seen as security issues, or just parts of the general development trends, depends, amongst others, on the applied security perspective. In Johansson (2011) it is argued that the negative consequences should be of a certain magnitude, unintended and unexpected (from the studied object’s perspective) to be classified as a security issue.

Other definitions of energy security more clearly include gradually changing conditions and also include aspects such as the economic viability and environmental impact of the studied energy systems in energy security analyses. This is for example the case when energy security is analysed within the form of the four A’s (availability, accessibility, affordability, and acceptability), presented by Asia Pacific Research Centre (2007) as a framework for energy security analyses, and which has been used for energy security analyses by for example Kruyt et al. (2009) and Hughes and Shupe (2011). Although the four A’s clearly overlap aspects of other policy areas, such as competitiveness and sustainability the approach can be useful in discussions regarding security aspects of RE.

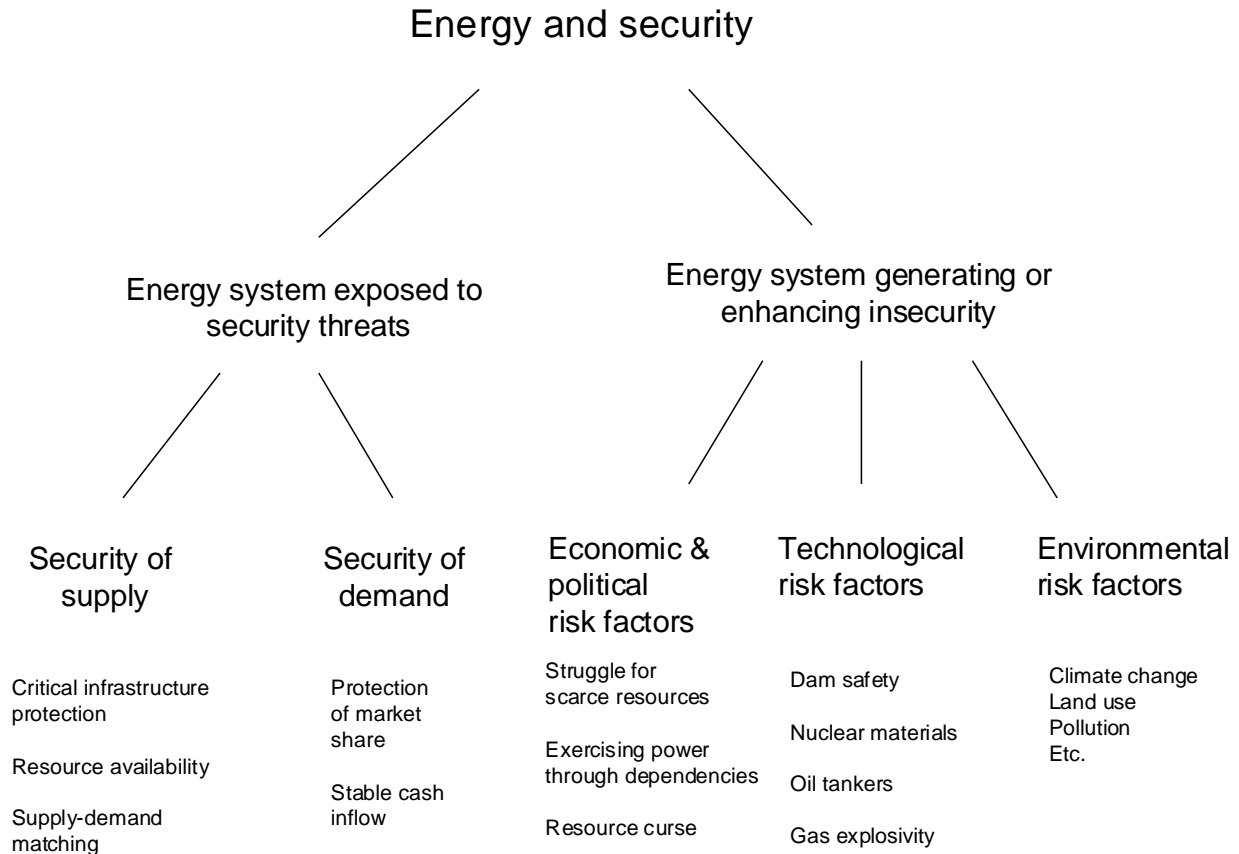


Figure 1. The analytical structure used in Johansson (2011) to study the relations between energy and security.

Potential strategies to improve security of supply could include a variety of measures such as:

- Increasing system diversity and flexibility. Here diversity and flexibility can relate to both energy sources and potential suppliers. Stirling (2010) furthermore characterises the diversity of the system by its variety, balance and disparity.
- Energy efficiency improvements reducing the sensitivity to price changes.
- Incentives for investing in extraction, conversion facilities and transmission and distribution infrastructure.
- Education and physical protection towards both unintentional and antagonistic threats to facilities and distribution systems.
- Energy storage and rationing systems.
- Securing access to energy (either through supporting the development of competitive markets or through direct control).

- Economic compensation systems.

The relevance of such measures depend on the type of threat, the geographic scale of the studied entity (global, national, regional or local) and whose security is in focus.

The dominating literature on energy security focuses on the geopolitics and dependencies on fossil fuels (especially oil and gas) and the functionality of electricity systems. The security aspects of renewable energy are seldom analysed and there exists a significant research gap in this field (Sathaye et al., 2011). In this paper it will not be possible to take a fully comprehensive approach including all aspects of energy and security indicated in Figure 1. Instead, some fundamental differences between RE and fossil fuel systems will be discussed in section 4 which will be complemented with a short analysis of three examples in section 5.

3. Renewable energy in the EU today and in the future

Renewable energy currently accounts only for about 8%¹ of total primary energy consumption in Europe, but the shares vary significantly among different countries from less than 5 percent in countries like the UK and Netherlands to more than 20 percent in countries like Sweden, Latvia, Austria and Finland, Fig. 2. Biomass dominates the renewable energy supply followed by hydro power. Within electricity production, hydro is the dominating renewable energy source followed by wind and biomass. During recent decades wind and solar power have increased significantly especially in countries like Denmark (wind), and Germany and Spain (wind and solar), while biomass-based transportation fuels have increased in several of the countries as a consequence of two subsequent EU directives. The successful development of renewable energy depends on several important aspects such as the availability of natural resources, strong policy commitment and the availability of suitable actors and technical systems, with a potential to react to these policies (Johansson et al., 2002). The countries with largest shares have a long history in renewable energy and usually possess significant forest resources, which are utilised in the forest industry as well as in residential buildings.

One example of successful development of renewable energy in the EU is found in Sweden where biomass currently contributes approximately 20% of total energy supply (Swedish Energy Agency, 2010). The use is dominated by black liquor in the forest industry and solid fuels used in industry, district heating systems and small-scale individual systems. The expansion of bioenergy in Swedish district heating systems has been remarkable expanding from approximately 25% of supplied energy in 1990 to about 70% to 2009 (Swedish Energy Agency, 2010). The introduction of a carbon tax in 1991 has been a main driver as it has totally changed the price relation between fossil fuels and biomass, while the relatively large district heating plants can utilise unrefined low cost biomass fuel which are relatively competitive compared to fossil fuels.

¹ While energy statistics traditionally presents RE shares as fractions of total primary energy *supply* the EU renewable energy directive refers to fractions of energy *demand*.

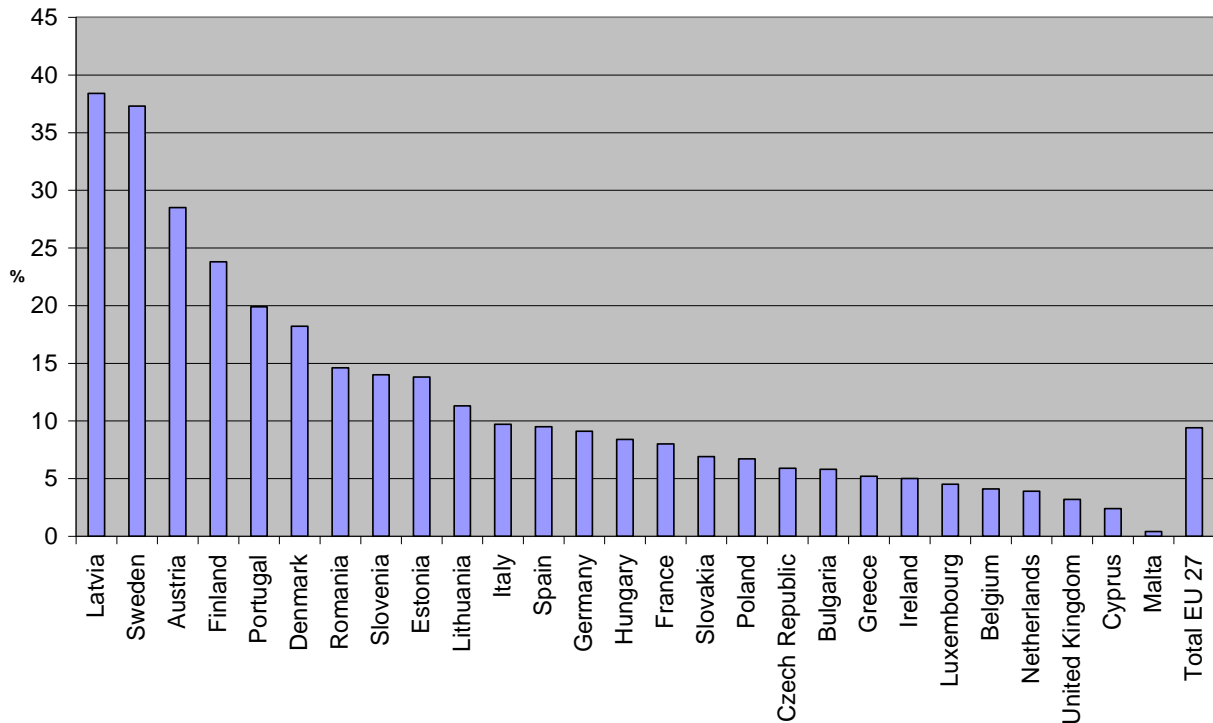


Figure 2. Renewable energy as fraction of gross inland energy consumption in EU countries 2009 (Euroobserver, 2011).

In the wind power arena, Germany, Spain and Denmark have been driving actors utilising feed-in-tariffs, which have provided the necessary stability for these alternatives to grow. In the field of transportation fuels there has been a significant expansion in some countries, but biofuels still do not reach more than 6-7% of total transportation fuels in any of the European countries (European Commission, 2011a)

So far the supply of renewable energy has been largely local or regional although there is some long-distance trade, both of solid biomass (Ericsson and Nilsson; 2004, Swedish Energy Agency, 2010) and of liquid biofuels.² The importance of trade will probably increase with growing demand for renewable energy.

The prerequisites for expanding renewable energy vary from country to country. The potential for biomass productions depends amongst others on climate conditions, soil, and available land areas (see e.g. Ericsson and Nilsson, 2006 and EEA, 2006 for estimates of biomass potentials). The per capita production potential could differ a factor 5-10 among EU countries (Ericsson and Nilsson, 2006). This indicates that there may be a driving force for biomass trade among EU countries but also for a growing import from outside the EU if incentives for climate mitigation are pursued. In a similar way the potentials for wind power vary among countries, but the

² In 2008 approximately 25% of the biomass-based transportation fuels used in the EU was imported (European Commission, 2011a). However, there was also a significant export from the union why the net import ended at 15%. Countries like the Netherlands, the UK and Austria depend heavily on import.

consequences of this may be less important, as the total potential in most countries significantly override the potential electricity demand, and the main restriction for utilisation is the possibility to integrate wind power in the system and the acceptance of wind power in local societies (EEA, 2009).

The possibility to generate a demand for biomass for heating and electricity also differs among countries. The existence of district heating systems, which in Sweden has proved to be pivotal for biomass expansion varies significantly among EU countries (Werner, 2005) as do the prerequisites to use biomass for co-firing in existing coal-fuelled power plants (Hansson et al., 2009).

Current EU policy targets for 2020 imply a doubling of RE compared to current levels corresponding to a 20% of final consumption by 2020. The target was proposed together with the ambition to reach a 20% reduction in CO₂ emission by the same year. The targets were not distributed equally for all countries but were based on current levels of RE and GDP levels of the different nations, see Table 1. The various conditions for renewable energy indicated above were also acknowledged through introducing flexibility mechanisms into the system by allowing Member States to count energy from renewable sources consumed in other Member States towards their own national targets.

In the longer term, GHG emissions have to be reduced significantly more and an 80% emission reduction has been proposed for the EU by 2050 (European Commission, 2011b). In the analysis that accompanies the EU Commission 2050 roadmap for a low carbon society, a significant increase in renewable energy is expected. According to this study, renewable energy could contribute approximately 50 to 55 % of total electricity by 2050 and 40-50% of transportation energy (European Commission, 2011b). Similarly, Johnsson et al (2011) estimate that renewable energy could reach 40% of final energy use by 2050. Several organisations argue that a totally renewable energy system is possible by 2050 (see e.g. the Danish Commission on Climate Change Policy, 2010 and WWF, 2011).

In most studies with a mid-term focus, interest is concentrated to biomass (including liquid biofuels) and wind power. This is mostly a consequence of their relative competitiveness. In the longer term, other alternatives may gain in importance such as solar power, solar hydrogen and electro-fuels (hydrogen or hydrocarbons produced from electricity through electrolysis). Such technologies could change the energy geography as countries with large resources and low cost electricity supply could be important providers of electro-fuels.

Table 1. Renewable energy as percentage of gross final energy consumption today and targets for 2020 (European Union, 2009a).

	Share of energy from renewable sources 2005	Target for share of energy from renewable sources 2020
	%	%
Belgium	2.2	13
Bulgaria	9.4	16
Czech Republic	6.1	13
Denmark	17.0	30
Germany	5.8	18
Estonia	18.0	25
Ireland	3.1	16
Greece	6.9	18
Spain	8.7	20
France	10.3	23
Italy	5.2	17
Cyprus	2.9	13
Latvia	32.6	40
Lithuania	15.0	23
Luxembourg	0.9	11
Hungary	4.3	13
Malta	0.0	10
Netherlands	2.4	14
Austria	23.3	34
Poland	7.2	15
Portugal	20.5	31
Romania	17.8	24
Slovenia	16.0	25
Slovak Republic	6.7	14
Finland	28.5	38
Sweden	39.8	49
United Kingdom	1.3	15
EU-27	8.5	20

4. Renewable energy versus “conventional” energy—some general characteristics and corresponding security aspects

Renewable energy, such as biomass, wind, and hydro, dominated energy supply before fossil fuels, around 1850, started to increase to dominate energy supply (IPCC, 2011). The main fossil fuel use was initially coal, but during the second half of 20th century oil took prominence as the most strategic fuel, being suitable for most purposes but especially having comparative advantages when used for transportation. Natural gas has during recent decades expanded rapidly as a clean fuel with low emissions of air pollutants that can be utilised with high energy efficiency.

The fossil fuels are stocks that are, in difference to renewable energy, gradually being depleted although the total available resources are still significant (see e.g. IEA, 2008 and Kjærstad and Johnsson, 2009). However, the most easily accessible resources are the ones first depleted which would imply increasing extraction costs and relatively greater environmental impact in the

future. The expected adverse effects of climate change, to which fossil fuel combustion is the main contributor, makes the environmental risk factor of fossil fuels significant.

Most of the reserves of oil and natural gas is concentrated in relatively few countries and have put these countries in the position to dominate the energy market. The five countries with largest conventional reserves hold approximately 60% of total reserves while only a minor fraction (10% and 20% for oil and gas respectively) is consumed in these countries (BP, 2009).³ This leads to dependencies between energy suppliers and energy consumers that are often highlighted as energy security problems although there is an on-going discussion as to the degree of importance that should be attributed to this factor (see e.g. Noël, 2008; Greene, 2010). The resource concentration also creates enormous flows of energy (and wealth) between regions. These flows could be sensitive to interruptions through accidents or various forms of attacks. Furthermore, the often untransparent market in reserve rich countries contributes to the instabilities of current oil markets (cf. Harks, 2010).

Nuclear in turn has its special security aspects related to technical risk factors such as radioactivity and the potential to use of nuclear materials for weapons. The security issues are thus connected to the risks for low probability accidents with potentially devastating effects and risks for nuclear proliferation (see e.g. Toth and Rogner, 2006; Jackson, 2009 and Ferguson, 2009). The security issues is thus of a totally different character than those found for fossil fuels and RE.

Although biomass have kept a 10% share of global energy supply the use is dominated (60%) by traditional biomass (IPCC, 2011). The development in industrialised countries goes, however, towards the use in larger centralised plants and more refined fuels. Also wind and solar energy undergoes a rapid increase both in the number of plants and plant size. Whereas wind power turbines in the beginning of the 1980s often rated about 100 kW in 2009 usually had a capacity 1.5-2.5 MW and are often grouped in wind power parks with power of several hundreds MW (Wiser et al., 2011). Hydro power has in some countries been the driver of electrification and still provides a significant fraction of produced electricity in countries like Norway, Sweden and Austria.

In contrast to fossil fuels, the renewable energy production potential depends, instead of on stocks, on the maximum annual flow which could be harvested without reducing the productivity. For biomass there are also restrictions from competing demands for food and fibre and the need to protect long-term productivity and other environmental values such as biodiversity (see e.g. Hoogwijk et al., 2003; Haeberl et al. 2011; Jackson 2011). If biomass extraction overrides these restrictions there might be a negative impact on both food and environmental security.

Renewable energy are much less concentrated the fossil fuels which is usually a negative from an economic point of view. At the same time certain quantities of RE are available everywhere which reduce the options for specific countries to gain similar exceptional positions in the global energy economy as those held today by some oil rich countries. There is, however, no guarantee that resources will match energy demand locally, especially in densely populated areas. The

³ Further development of shale gas resources will, however, have an impact on the geography of natural gas.

resources required for renewable energy production (solar influx, soil quality and water availability) are neither evenly spread nor correlated to demand.

Renewable energy systems are often viewed as local systems and therefore assumed to be more secure. However, many renewable energy systems gain economically from international trade and from investments in energy transmission systems, thereby enabling the utilisation of the varying opportunities for energy production as well as advantages of scale which exist at least for some technologies. New energy transport routes will provide new and different security threats which might be difficult to predict in advance.

Accessibility, to renewable sources depend on the development of transmission system from sources to consumers and the availability of adequate technologies for end-use such as charging equipment for electric vehicles or smart grid systems balancing supply and demand for variable energy systems.

The affordability of an energy source is a matter of definition. Most renewable energy carriers are, at least in the short run, more expensive than its fossil counterparts (cf. solid biomass vs. coal or ethanol vs. petrol). Including external costs for environmental impact can change this, as will technology development and learning effects that make RE more competitive and affordable as markets grow (see e.g. IPCC, 2011). Also, if economies continue to grow also more expensive systems will be affordable (see e.g. Johansson, 2009)

Wind power and solar energy is characterised by their variable production which depends on non-anthropogenic factors such as cloudiness, wind, and the daylight. This will create new challenges for the electricity system which will be discussed in the following chapter.

Technologies used to harvest and utilise renewable energy efficiently could create new dependencies of scarce or at least geographically concentrated materials such as neodymium for wind power plants, lithium for car batteries⁴ and scarce earth metals for solar cells (see e.g. Andersson, 2000; Råde, 2001). Many of these materials could be substituted by other, more abundant resources; however this may come at an economic cost. The long-term supply of these metals will also depend on the development of efficient recycling systems.

Finally, with regard to the environmental sustainability of various energy sources focus has for fossil fuels traditionally been directed towards emissions of air pollutants such as CO₂, SO₂, NO_x and VOCs. Renewable energy has been seen as an important opportunity to manage this problem especially through lower emissions of CO₂ and SO₂. However, “new” environmental factors such as threats to natural landscapes by wind energy or biomass and the stress that intensive utilisation of biomass might have on biodiversity will grow in importance as renewable energy grows.

Introducing renewable energy sources will increase overall diversity of the national or EU energy system making them less vulnerable to supply disturbances or price volatility.⁵ For the individual consumer, diversity on a societal level may be of less importance since he or she

⁴ Electric vehicles are often seen as a resource in utilising renewable energy in the transportation system and as storage resource to integrate variable electricity in the system.

⁵ Some “fuel-free” technologies, such as solar and wind electricity systems, are, when built, insulated from fluctuations in fuel markets (see eg. Ölz et al., 2007).

might be stuck with single systems. Connection to diversified systems like district heating⁶ or electricity systems could be one solution. Another would be to introduce redundancy by using double heating systems or flexible fuel vehicles. However, all redundancies come at a cost.

5. Security aspects of some renewable energy systems

In previous sections, general discussions were conducted regarding the security aspects of renewable energy. In this section a more deepened discussion is carried through regarding three potential development directions in the field of renewable energy. The areas discussed are i) an increased use of transportation fuels from biomass, ii) the increasing dependence on variable electricity production and iii) the development of large-scale solar electricity plants in Northern Africa intended to supply a significant fraction of European electricity.

5.1 Transportation fuels from biomass

Renewable transportation fuels have played a significant role in countries such as Brazil and the US for several years. Also within the EU the demand has increased significantly during recent years, to a large extent as a result of the implementation of the biofuel directive of 2003 (European Union, 2003) and the renewable energy directive of 2009 (European Union, 2009a). The development has varied significantly among various countries depending on the degree of acceptance of the policy direction and the consequently implemented policy instruments (Di Lucia and Nilsson, 2007). The renewable fuels, so far mainly biofuels, are heavily dependent on tax subsidies or other policy instruments to be competitive. Although, most of the transportation fuels consumed in the EU (mainly biodiesel and ethanol) are produced within the Union from agricultural products, significant quantities are imported from countries like the US and Brazil which can produce the fuels more cheaply and with lower carbon emissions (Börjesson et al., 2009). With a continuing increase in transportation fuels demand, there are many reasons to believe that a larger fraction will be supplied by countries in with better production conditions than EU countries.

Thus, although the substitution of biofuels for fossil fuels will reduce the dependence of certain oil producing countries, new dependencies will arise. New transportation routes from Latin America and Africa may arise which will have to be protected from natural and antagonistic threats.

Much of the biomass-based fuels are used in the form of blends in conventional fuels and new EU regulation has allowed higher fractions of ethanol in petrol and Fatty-methyl esters (FAME) in diesel (European Union, 2009b). In some countries there is also an expansion of flexible fuel vehicles allowing choosing the fuel which at the moment is cheaper. The direct dependence of the development in the oil markets is thus reduced. There is, however, an indirect dependence as

⁶ In district heating systems, biomass is used in boilers or cogeneration plants which interact with other plants such as oil fuelled boilers, which could function as backups for each other. Also solar energy could be connected to such centralised systems. The possibility to utilise various energy sources within the district heating systems reduce the vulnerability to disturbances in fuel supply and to price variations. However, if the system is built to depend mostly on a single renewable energy source the vulnerabilities remain.

there is a correlation between prices on biofuels and petroleum (Hedeneus et al., 2009). Higher petroleum prices globally lead to a higher demand of biomass-based transportation fuels with higher prices as an expected result. This means that a biofuel consumer is not insulated against disturbances in petroleum markets.

The expansion of biomass-based transportation fuels has been challenged from a sustainable development perspective for at least two reasons. First, some modelling exercises indicates that there is a risk that increased development of biomass energy leads to indirect emissions through secondary changes in land-use for example intensification of the use of meadow lands and increased felling rates of rainforests. Second, increasing food prices (for example the development in 2005-2008, have at least partly been attributed to the expansion of biomass-based transportation fuels.

The importance of an expansion of biomass-based transportation fuels for food security depends on several important aspects. The demand of land for food production (and as a consequence the availability of land for energy) is a result of amongst others population growth, diet, productivity changes etc (Hoogwijk et al., 2003; Haeberl et al, 2011). Furthermore, often food insecurity do not depend on too small global food production but on the lack of economic resources for poor people preventing them from the access to food, war and civil unrest (see e.g. Sen, 1999; Fajj, 2008). To reduce the conflicts it will be important to utilise waste streams for second generation biofuels as well as more efficient conversion technologies. However, all together, a growing population, dietary changes, and increasing demand for renewable fuels and fibre might lead to and a land scarcity in the future with rising costs for produced transportation fuels and food. This could require improved institutional systems for resource distribution.

In response to the challenges, EU introduced sustainability criteria in the renewable energy directive (European Union, 2009a), with the aim to safeguard the environmental credibility of the transportation fuel systems. It prohibits the production of biomass-based fuels from certain types of land and also requires that fuel companies can assure that GHG fuel-cycle emissions do not exceed certain specified quantities. The backside of such a system is that it requires a significant bureaucracy for evaluating the supply system and there will always be difficulties to fully take into account indirect effects on global land use. Thus, although the sustainability criteria might in the short run prevent the worst examples of negative land use effects, in the longer run other systems of governance will be required that target the land use effects at the local level where the actual impact on carbon balances and valuable ecosystems occur (Van Dam et al., 2010). Although such governance systems have to be implemented on local or regional levels, they can certainly be a part of larger climate regulation systems. Those suffering from necessary restrictions on land use (often poorer countries) could then be compensated by more prosperous countries (see e.g. Schubert et al., 2009). Systems that directly balance support for biofuels with restrictions on the use of environmentally valuable land have also been proposed (Killeen et al., 2011).

5.2 The growing importance of variable electricity production

A significant expansion of renewable energy for electricity production is expected in the coming decades within EU. Much of the anticipated expansion of renewable electricity in the future is

based on biomass-based power, wind power and solar power. Traditionally these systems have been small-scale but as mentioned above the size of plants have increased for economic and planning reasons

Introducing renewable energy will increase the diversity in electricity systems dominated by fossil fuels and reduce the dependencies of especially imported oil and gas. Some electricity systems within the EU are, however, already today rather independent of fossil fuels for its production. However, electricity prices are not even in these systems price insulated from the development on fossil fuels as national electricity systems are interconnected. For example, Swedish electricity prices are usually driven by the production costs of coal-based electricity in Denmark even though the electricity production in the country is in principle fossil free.

With a growing amount of variable electricity the fundamental task for the electricity system, to match supply and demand, will get more complicated (see e.g. Sims et al., 2011 ; Purvins et al., 2011). This will put significant requirements on back-up technologies and investment in extra transmission infrastructure. The back-up systems can be Scandinavian storable hydro power reserve plants and energy storage facilities as well as smart systems for demand-side management. These could include everything from adaptation of industrial production levels, scheduling appliance use in response to current prices, and controlled release of electricity from batteries in parked electric vehicles (see e.g. Kempton and Tomic, 2005; Andersen et al., 2009). The systems could gain from the rapid development of information technology (see e.g. Battaglini et al., 2009) and new tariff structures. It should, however, be noted that smart grids could introduce new security threats, see e.g. McDaniel and McLaughlin (2009).

5.3 Solar electricity from North Africa

A vision to utilise solar energy from North Africa for European energy demand, has in small steps started to be made concrete through policy plans and private initiatives (see e.g. Fritsche et al., 2011). The background is that, to supply Europe with most of its energy, it would be enough to dedicate only a small fraction of the desert areas for solar energy. This would allow avoiding many of the planning challenges connected to European wind, solar and biomass energy. North African solar electricity could provide base power for the European electricity system but also be used for hydrogen production, desalination of drinking water and improvement agriculture locally.

One concept is the Desertec joint venture initiative which aims at producing 15% of Europe's electricity demand with solar power in North Africa (Lilliestam and Ellenbeck, 2011). Surplus production is expected to be used for hydrogen production and desalination of sea water for providing drinking water and improving agricultural conditions.

With the production of solar electricity in North Africa, EU will be dependent on electricity production outside its borders. It has been argued that with such great energy dependence a major disturbance could threaten the stability of all the European power system. Notably, production plants and transmission infrastructure will be localised in countries that today are not

regarded as politically stable (Johansson et al., 2010).⁷ The potential disturbances could be disruptions of energy supplies by governments as well as attacks by non-state actors on infrastructures (Lacher and Kumetat, 2011). Lacher and Kumetat conclude that North African states have overall been reliable energy exporters and that intentional supply disruption is unlikely for political and economic reasons. Although solar plants in remote areas could become a target for insurgency they are unlikely to seriously harm the project as a whole or cause major and sustained electricity disturbances. Grids lines are the most vulnerable component but Lacher and Kumetat but the impact of an attack would generally be short-lived. Lilliestam and Ellenbeck (2011) conclude that Europe will be susceptible to extortion and political pressure only if all exporter countries unite in using the energy weapon. Worth noting is that if solar electricity is used as a substitute for natural gas powered it would reduce the dependence of Russian gas currently often viewed as an important security risk (see e.g. Stegen, 2011).

Much of the security aspects related to the solar power systems in Northern Africa depends on whether mutual interest between supplier and consumer can be harvested (Lacher and Kumetat, 2011). If the project is connected to desalinisation of sea water for providing drinking water and irrigation and contributes also to local electricity demands it could contribute to local development and perhaps stabilisation of the countries (Johansson et al., 2010). So the security aspects of such a project may very well lie in the details.

6. Concluding discussion

Renewable energy will affect security and societal resilience in various ways. The impact depends on the type of energy resource, the system design and the institutions and regulations surrounding the technology.

The main advantage of RE from a long-term energy security perspective will be the fact that RE is based on flows instead of exhaustible stocks. In general more renewable energy in the system can increase diversity making the system less sensitive towards some types of disturbances. This increase in diversity is relevant with regard to energy source and supplier. The fact that all countries possess at least some renewable resources the development of RE could secure at least some energy supply even if the global system is under severe strain. However, for economic and other reasons, the development of centralised systems like Desertec could be motivated but it will simultaneously lead to new interdependencies.

Energy independence is often highlighted as a target in itself. However, dependence of a single local supplier might be as sensitive as the dependence of a broader regional or global market. This holds especially for RE resources which depend on long-term climate and short-term weather developments. Increasing use of variable electricity will be helped by electricity system integration as it would enable the utilisation of the geographical variability of wind and sun. Ever increasing fractions of RE can also affect institutional conditions. New technologies could gain from effective pricing systems affecting both demand and supply in response to increasingly

⁷ Most of the literature in the field has so far been written before the overwhelming changes that took place during the so called Arab spring 2011.

fluctuating supply. Furthermore, on a more general level it is not evident that energy *independence* provides greater security than *interdependencies* among states.

For RE as well as for conventional systems there will always be a trade-off between security and economic efficiency. Security of supply can for example usually improve with redundant transmission and distribution systems, by reserve production plants in district heating systems and investing in supplementary energy systems in the form of combined heating systems and flexible fuel vehicles.

Streamlining and adapting renewable energy carriers to the current fossil-fuel based systems are feasible strategies for expanding RE but will as a consequence make RE markets dependent on parallel fossil fuel markets. Although prices on locally produced renewable energy could not be sheltered from the developments on the global energy markets the local economy could be less sensitive as the extra costs for energy consumers in the area could at least partly be balanced by larger income streams. Furthermore, renewable energy will be at least as dependent on well-functioning technological systems, especially as RE in many scenarios (see e.g. European Commission, 2011b) is seen as especially well-suited for electricity production.

The income aspect could be of interest when discussing the advantages and disadvantages in importing biomass from developing countries and its potential conflict with food security. Although there will might be rising prices on food products and land from an increasing demand on biofuels, all other equal, this will also give rise to new incomes for the population. It seems not to be an ultimate end to keep food prices low as it may encourage low efficiency in the food system, leading to higher demand on agriculture land and increased strain on ecosystems. Instead it seems to be more important to create adequate institutions that ensure that populations are provided with resources to buy food and other necessities.

Institutions will furthermore be essential to prevent biofuels from affecting biodiversity and long-term production conditions negatively. The effects are place specific and are probably best governed on a local basis but the necessary local regulation will have to be connected to global governance systems since the consequences are global and that there might be motives for directing some of the costs for the restrictions occurring in developing countries to developed countries.

Although RE in the short term can improve energy diversity, it seems that it is mostly the lower impact on climate change and the need in the long-run to depend on flowing resources that will motivate the turn to renewable resources. For economic reasons and to keep the potential stress on the biological resources low it will be essential to use the resources efficiently and energy efficiency measures will thus be as important in systems heavily reliant on RE as for current systems dominated by fossil fuels.

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