Bioenergy Trade in a Changing Climate

- a review of mitigation-adaptation inter-relationships from a Nordic perspective

Olle Olsson and Francis X. Johnson

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Olle Olsson[1] and Francis X. Johnson[2]

[1] Stockholm Environment Institute, Linnégatan 87D, SE-11523 Stockholm, Sweden.

Email: olle.olsson@sei-international.org

[2] Stockholm Environment Institute, Linnégatan 87D, SE-11523 Stockholm. Sweden
Email: francis.johnson@sei-international.org

ABSTRACT

Although the climate mitigation implications of bioenergy trade have been analyzed fairly extensively in recent years, inclusion of climate adaptation in such analyses has hitherto been rare. This working paper provides an overview of mitigation-adaptation inter-relationships relating to bioenergy systems and bioenergy trade based on the situation in the Nordic countries (Denmark, Finland, Iceland, Norway and Sweden). Given the increasingly international characteristics of bioenergy markets, global aspects are covered to a certain extent as well. Climate change is likely to impact all stages of bioenergy supply chains. Increased prevalence of droughts and pests can impact cultivation systems for energy crops, warmer winters can reduce need for bio-based heating and fuel supply systems can be disrupted by flash floods. The overall impacts on bioenergy markets in Nordic countries are however most likely to be benign, with climate change resulting in increased biomass productivity while at the same time reducing demand. This means that the Nordic region could grow in importance as a supplier of renewable energy for e.g. parts of Europe that will be adversely affected by climate change. However, the Nordic countries are currently substantial importers of bioenergy, which means that not only are they exposed to climate change impacts on global bioenergy supply chains, their demand for bioenergy can also indirectly impact adaptive capacities in other regions. Increased understanding of the inter-relationships between bioenergy markets and climate change risks and responses—for both mitigation and adaptation—is imperative to ensure long-term sustainability of bioenergy as a valuable component in low-carbon futures.

Acknowledgments

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1 Introduction

1.1 Background

Regardless of the level of success of efforts to mitigate anthropogenic climate change, a certain level of climate change will be inevitable. It has become increasingly clear in recent years that in addition to mitigation, adaptation to climate change therefore has to be an integral part of strategies to reduce climate risks (IPCC 2007). According to available scenarios, the Nordic countries – Denmark, Finland, Iceland, Norway and Sweden – do not seem to be among the most vulnerable regions in terms of adverse effects from climate change. In fact, the Nordic countries have among the highest adaptive capacities among European regions (ESPON 2011) and climate change is also likely to bring opportunities, through increased productivity in agriculture and forestry. However, there are still non-negligible climate risks in the region that need to be addressed, including more severe extreme one-day precipitation events and rising sea levels (Klein and Juhola 2013).

An additional factor to consider is that all the Nordic countries are small and open economies, which means that they are very intertwined with the world at large. Globalization means that climate change can have indirect effects in places that are geographically very distant from the actual point of impact. In other words, although adaptation is generally seen as more site-specific in contrast to the global scale of mitigation, local climate impacts can have global consequences and thus adaptation as a concept should not be limited strictly to a regional focus (Benzie et al. 2013).

It is also imperative to take adaptation aspects into account in order to ensure the long-term viability and sustainability of climate change *mitigation* strategies. One mitigation option for which this is especially important is bioenergy. There are several reasons why this is the case.

- Bioenergy is a vital component of global climate change mitigation strategies (Edenhofer et al. 2010). Although its share of renewable energy is expected to decrease, bioenergy will have to play an important role if low stabilization scenarios for 2050 are to become reality (Chum et al. 2011). The importance of bioenergy is even more significant in the shorter timeframe, as can be seen from developments at the EU level. Bioenergy is expected to contribute with more than half of the increase in renewable energy from 2005 to 2020 as stipulated by the European Union in its Renewable Energy Directive (AEBIOM 2012).The share of bioenergy in final energy consumption in the EU is expected to increase from 5.4% in 2005 to 12% in 2020 (Atanasiu 2010).
- The reliance of bioenergy systems on land use means that bioenergy supply chains are dependent on, and can be vulnerable to, weather patterns and climate change (Smith et al. 2007). At the same time, a growing demand for bioenergy can also support adaptation in agriculture as several crops commonly used as bioenergy feedstock also have properties that are important for climate change adaptation, including drought resilience and water efficiency (Berndes 2008).
- Solid and liquid biofuels are increasingly becoming globally traded commodities (Junginger et al. 2013). This means that European or Nordic mitigation strategies based on bioenergy cannot be evaluated strictly from a European/Nordic perspective. In particular, the inherent climate dependence of bioenergy supply chains necessitates that the interaction between bioenergy and adaptation in other parts of the world also needs to be taken into account when designing bioenergy-based mitigation policies.

This working paper aims to review the research on mitigation-adaptation interactions in relation to bioenergy markets in general and bioenergy trade in particular, thus including all stages of the supply chain in the analysis from cultivation and production through logistics and transportation to end-user demand. Focus is on the "modern" bioenergy systems that are of most relevance to the energy situation and energy policies of the Nordic countries. Thus, traditional use of biomass as an energy source is covered only briefly. However, given the increasingly international characteristics of bioenergy markets, certain global (i.e. non-Nordic) climate impacts on bioenergy supply chains and possible adaptation-mitigation inter-relationships are included.

1.2 Outline of the working paper

This working paper is structured as follows. **Chapter 2** gives a brief overview of bioenergy markets and international bioenergy trade. **Chapter 3** introduces the current status of renewable energy in general and bioenergy in particular in Denmark, Finland, Iceland, Norway and Sweden. The chapter also presents the respective strategies of the five countries for continued expansion of bioenergy as mandated by the EU Renewable Energy Directive. **Chapter 4** presents the two concepts mitigation and adaptation, with special focus on the potential synergies and conflicts between the two. **Chapter 5** discusses the impact from climate change on bioenergy markets and **Chapter 6** presents available research on possible mitigation-adaptation synergies and conflicts in the context of bioenergy trade. **Chapter 7** concludes and offers suggestions for areas that require further research.

2 International bioenergy markets

2.1 Biomass, bioenergy and biofuels

In this working paper, the term "bioenergy" is used to designate all energy derived from biomass. Bioenergy can come in different physical states, including solid (e.g. wood pellets), liquid (e.g. bioethanol) or gaseous (e.g. biomethane) and can be used for a wide variety of purposes, be it as transportation fuel (biofuels), heat production (bioheat) or electricity generation (bioelectricity). Note that the term "biofuels" is herein restricted to designate liquid biomass-based fuels used for transport (AEBIOM 2012). Focus is on internationally traded fuels, which means that gaseous forms of bioenergy will not be covered[1].

The use of biomass for energy purposes is by no means a novel phenomenon. For thousands of years, mankind has used biomass for the provision of heat, cooking fuel and in later years electricity and transportation fuel (Smil 1994). Traditionally utilized biomass is still a vital source of energy for heating and cooking for many millions of people around the world today. In total, bioenergy provides about 10% of global primary energy supply, out of which traditional bioenergy makes up more than 60% (Chum et al. 2011).

However, bioenergy utilization has in recent decades begun to take new forms. High fossil fuel prices, concerns about security of energy supply and ambitions to mitigate anthropogenic climate change have resulted in a renewed interest in the use of biomass for energy purposes. This has led to a transformation of bioenergy utilization on both a technological and organizational level. One of the more notable developments is how advances in technology and logistics – coupled with a general growth in the demand for renewable energy – have enabled the establishment of long-distance trade in bioenergy. Whereas bioenergy markets have traditionally been quite limited geographically, bioenergy is now traded on a global level (Junginger et al. 2013).

2.2 Bioenergy markets and climate policy

In order to understand mechanisms of bioenergy markets and policies relating to bioenergy markets, it is important to note that bioenergy has certain characteristics that distinguish it from other renewable energy sources such as solar, wind or hydro power.

2.2.1 Key characteristics of bioenergy markets

To begin with, bioenergy markets are intrinsically interconnected with several other established markets. This is partly in its capacity as a renewable source of energy, where it is a possible substitute to other energy sources, fossil and renewable. Perhaps even more important however is that the raw material sources from which bioenergy is extracted – be it forestry, agriculture or municipal solid waste – all have many alternative uses. Thus, bioenergy markets also interact with agricultural markets, forest products markets and waste management systems. Consequently, bioenergy policy also interacts with these markets, not to mention the policies governing them, most notably agricultural and forest policy (Chum et al. 2011; Olsson and Hillring 2012).

[1] There are reports of cross-border trade in biomethane (Kovacs 2013), but these markets are only in their very infancy in comparison to markets for liquid and solid biomass-based fuels.

Another fundamental difference between bioenergy and other established renewables is that bioenergy comes in the form of gaseous, liquid or solid *fuels*. This means that there are many similarities between bioenergy and fossil energy, not only in a chemical sense but also when it comes to the technological systems used. A result of the similarities between fossil fuels and biomass-based fuels - including the fact that biomass offers stored energy just like fossil fuels – is that bioenergy tends to be easily integrated into fossil fuel technology and infrastructure[2] (Chum et al. 2011). The fact that bioenergy can be delivered as fuels also means that it can be converted to a wide range of energy carriers (including electricity and heat but also hydrogen). It can also easily be *traded* on a global level (Junginger et al. 2011), which arguably is one of its distinguishing features compared to other forms of renewable energy.

2.2.2 Bioenergy markets & bioenergy policy

Bioenergy systems hence combine three key features:

- High degree of interaction with markets for energy, forest products and agricultural produce
- Simple implementation through integration into existing infrastructures
- Rapidly growing degree of market internationalization

In essence, this means that bioenergy systems may be relatively simple to establish, whereas the actual functioning and mechanisms of ensuing markets are highly complex. These features are a key factor when it comes to understanding the controversies surrounding bioenergy markets that has been a continuous source of debate in recent years (Brännlund et al. 2010; Rosillo-Calle and Johnson 2010; Berndes et al. 2013).

The ease by which bioenergy can be introduced into already existing market structures is an important reason for its prevalence in policy strategies aiming to reduce the use of fossil fuels and mitigate climate change (Chum et al. 2011). However, the actual reasons why countries have used bioenergy to wean themselves off fossil fuels have varied over the decades. The first wave of promotion of modern bioenergy came in the wake of the oil crises in 1973-1974 and 1979-1980 when bioenergy was seen as beneficial primarily because of its potential to reduce dependence on imported energy. Many of the policy measures that later have resulted in international trade in solid and liquid biofuels, were originally implemented with the purpose to stimulate *domestic* bioenergy supply as a means to increase energy security. The recent emergence of large-scale international trade in bioenergy seems to have developed largely as an unforeseen consequence rather as a conscious strategy of policy makers (Franco et al. 2010; Lamers et al. 2011). This is likely to be an important factor that helps explain the general absence of comprehensive and stable bioenergy policies, not least in the EU (Westberg and Johnson 2013).

The integration of bioenergy into existing market systems means that there are plenty of already established market actors continuously seeking the most cost-efficient and profitable methods to adjust to policy frameworks mandated by governments on national and supranational levels (HEC/CABI 2010). A consequence of this is that the effects (intended or unintended) of bioenergy

[2] Two examples of such integrations are blending of bioethanol with petrol for use as automotive fuel and the co-firing of wood pellets with coal for production of heat and electricity.

policies become visible very quickly. As weaknesses and loopholes in policy design or policy implementation thus rapidly are revealed, policy makers continuously find themselves in a reactive rather than a proactive position (Lamers et al. 2011). Instead of setting predictable and long-term rules within which markets can develop and function, policy makers have continuously had to respond to previously unforeseen effects from bioenergy market developments, either to new developments in research - such as the recent focus on the potential problems of ILUC, Indirect Land Use Change (Berndes et al. 2013) - or from market spillover effects, including food price increases resulting from growing demand for food crops for energy purposes (Johnson et al. 2012; Persson 2014).

Failure to fully anticipate the effects of - and public reaction to – possibly well-meaning but ill-designed policies aiming to support bioenergy development has thus become a reoccurring phenomenon. Most attention on the possibly adverse effects of increased demand for bioenergy has been directed towards liquid biofuels based on agricultural crops. The short rotation times in agriculture (i.e. compared to forestry) and consequential flexibility in changing between crops means that the effects on the ground from changes in market conditions rapidly become apparent. In addition, there are obviously strong emotional connotations attached to all discussions on using food crops for non-food purposes, especially in the context of worries about global food security (Gomiero et al. 2010).

This has resulted in several cases where policy makers on national as well as EU levels have, under pressures from public opinion and NGOs, had to make several ad hoc modifications to policies already under implementation. With market actors in vital need of a stable long-term regulatory framework to take the substantial economic risks, the unpredictability of bioenergy policy is becoming an obstacle to the realization of bioenergy as a sustainable energy path and as a means of GHG mitigation (Johnson et al. 2012)[3]

2.3 International bioenergy trade: overview

Bioenergy trade allows regions rich in biomass resources and/or technology platforms to exploit their comparative advantages and thereby improve overall economic efficiency. Through trade, efficiency can be gained by importing goods that are produced with higher quality and/or lower cost elsewhere instead of producing the same goods domestically. Additionally, interaction with other geographical markets enables hedging of risks related to supply as well as demand (Nelson et al. 2009).

The rationale for trade in bioenergy is thus the same as for trade in general. For example, wood pellets are imported to the European Union from North America because they constitute a less expensive source of supply than pellets produced within the EU, despite the additional costs of transatlantic transport (Trømborg et al. 2013). Trade exploits the comparative advantage of one

[3] It should be recognized that the principal issues leading to discussions surrounding the effects of an increased demand for biofuels are valid also for other forms of bioenergy such as solid fuels based on forest biomass. There has been plenty of discussions in the Nordic countries about the impact on traditional forest industries from increased demand for wood-based bioenergy (Brännlund et al. 2010).

region over another in terms of the cost of inputs, the availability of market distribution channels and infrastructure and other factors that facilitate reliable supply in relation to demand.

Both liquid and solid biofuels are traded internationally to significant extent. The emergence of international trade in bioenergy is a process that has taken place mainly in the first decade of the 21st century in parallel with the rapid growth in demand and corresponding production volumes. From 2000 to 2009, global production of bioethanol increased from 340 PJ to 1540 PJ. At the same time, the global biodiesel market grew from less than 30 PJ to more than 572 PJ, while total wood pellet production went from 8.5 PJ to more than 100 PJ (Lamers et al. 2011; Lamers et al., 2012).

2.3.1 Trade in biomass-based commodities in general

Bioenergy markets are closely related to markets for agricultural commodities and forest products in general. One example of this is that it can be difficult or even impossible to separate trade in bioenergy from trade in non-energy biomass. For example, the primary purpose of trade in high quality saw timber is for use in, e.g., construction, but it will also provide energy as sawmill residues in the form of sawdust, chips and bark are combusted within the sawmill itself or sold externally (Kalt and Kranzl 2012; Olsson and Hillring 2013).

Inter-dependencies can also be seen in the end-use markets for biofuel raw materials, especially vegetable oils used for production of biodiesel. Palm oil and soybean oil are both used as raw material in biodiesel production, but this only makes up small fractions of the markets, with the vast majority of demand coming from the food sector (Sanders et al. 2012). The point here is that in addition to the trade in commodities that are traded with energy as an explicit end-use there are large trade flows in both agricultural and forest products that may or may not include cargos that will be used for energy purposes.

In order to make international bioenergy trade economically viable, well functioning logistics systems are crucial. Compared for example to fossil fuels, biomass-based commodities are in general quite complicated when it comes to transportation, handling and storage, which can be clearly exemplified by comparing the logistical properties of coal and wood pellets. Firstly, the energy density is significantly lower for pellets, which means that significantly larger volumes need to be transported for any give amount of energy required. Secondly, pellets are vulnerable to moisture and tend simply to dissolve if exposed to moisture. Thirdly, there have been repeated reports of the deaths of crewmembers on ships transporting pellets, due to carbon monoxide poisoning (Deutmeyer et al. 2012).

2.3.2 Bioethanol

Although there is evidence showing the advantages of bioethanol as a substitute for traditional firewood as cooking fuel in developing countries (Schlag and Zuzarte 2008), consumption of bioethanol for energy purposes is dominated by its use in road transportation. The global bioethanol market is to a very large extent dominated by two countries: the United States, where bioethanol is predominantly produced from corn (maize), and Brazil, in which the industry is based on sugar cane. These two are both the largest producers and consumer of bioethanol, together accounting for 87% of the market. Also, production in both countries is primarily aimed at the domestic market. Hence, the share of net international trade in bioethanol relative to the total size of the global market was only 2-3% in 2009 (Lamers et al. 2011). This share might increase in the future as there is a growing trade in bioethanol between the US and Brazil. This is partly to compensate for seasonal differences in production cycles, but also a consequence of discrepancies in policy design in the two countries. The US Renewable Fuels Standard mandates a specific share of “advanced” bioethanol, among which Brazilian sugar cane ethanol is the only alternative that is widely available. This has led to an increase in the export of Brazilian ethanol to the US and concurrently an increase in the export of US corn ethanol to Brazil, as well as to the EU (Meyer et al. 2013).

2.3.3 Biodiesel

The biodiesel market has hitherto primarily been a European matter. There are mainly two reasons for this: *a)* EU policy measures aimed at increasing the share of renewable energy used for transportation and *b)* the high penetration of diesel-powered automobiles in the European market. In 2012, 55% of all cars sold in the European Union were diesel-powered (ACEA 2013). For comparison, the share was only about 5.5% in the United States (Diesel Technology Forum 2013). In Europe, diesel makes up about 70% of road fuel consumption and gasoline about 30%, whereas the situation is approximately the other way around in the US, see Figure 1.

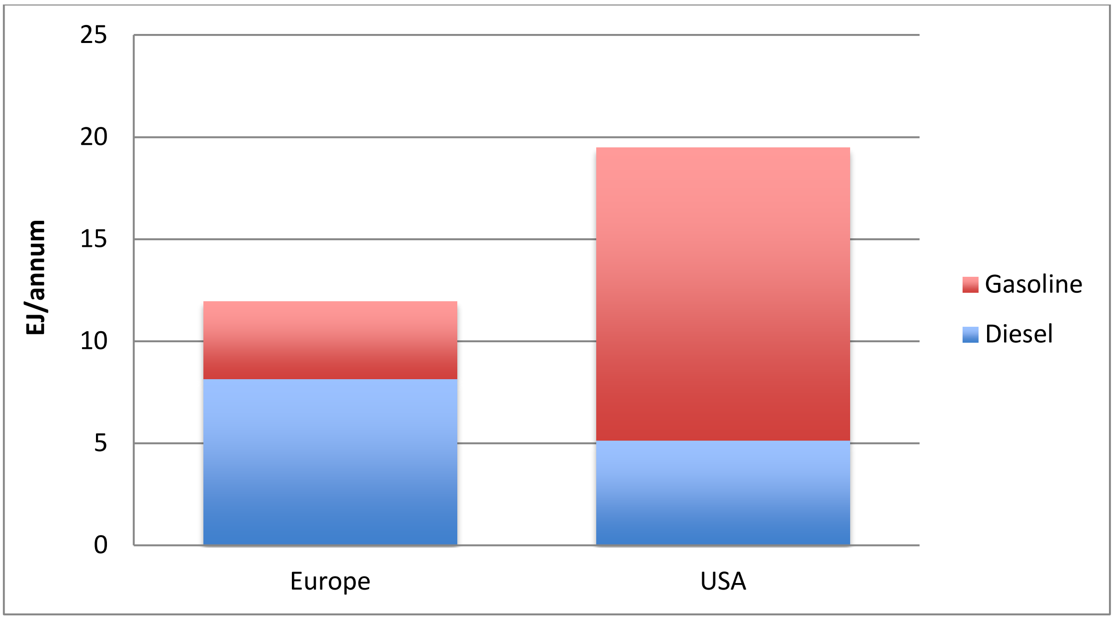

Figure 1. Consumption of diesel and gasoline in road transportation in Europe and the US in 2010. (Data source: World Bank, 2013)

Correspondingly, more than 70% of global biodiesel consumption took place in the European Union in 2009. The EU is also the largest importer of biodiesel and make up the lion’s share of international trade, which accounted for about 14% of global production in 2009. The US is the largest exporter of biodiesel, followed by Indonesia, Malaysia and Argentina (Lamers 2012). However, it is important to note that there is also a large international trade in raw materials for biodiesel production in the form of different kinds of vegetable oils (Johnson 2011).

2.3.4 Wood pellets

In the market for solid biofuels, wood pellets is by far the fuel category that has seen the most rapid growth in the recent decade, in terms of both total market volumes and international trade. Wood pellets can be used for production of heat and/or electricity in a wide variety of applications, ranging from small-scale boilers for detached houses to large-scale production of electricity. It should however be emphasized that the vast majority of international trade in wood pellets is destined for large-scale production of electricity (Sikkema et al. 2011).

The largest producers in the world in 2012 were the US and Germany. The wood pellet market is to a large degree a European market, and US production is primarily directed export to electricity utilities in the European Union, although in the US North-East there is also substantial domestic market for residential wood pellets. Recent years have seen rapidly growing consumption of wood pellets in large power stations in Denmark, the Benelux countries and especially the United Kingdom. In the UK, conversion of power stations from coal to wood pellets is leading to a situation where some individual UK power plants each consume an amount of wood pellets equal to or above that of the entire country of Sweden (Verhoest and Ryckmans 2012). Between 2012 and 2013, annual wood pellet consumption in the UK is estimated to have increased from 1.3 million tonnes to more than 4.5 million tonnes (AEBIOM 2013).

A substantial intra-European trade and especially the large and growing transatlantic trade flows combine to make wood pellet markets quite internationalized. In 2010, 44% of all wood pellets produced were traded internationally (Lamers et al., 2012). This share is likely to grow with the rapid expansion of EU imports from North America.

2.3.5 Wood chips

The market size of wood chips used for energy purposes is difficult to assess to a satisfactory degree. There are several reasons for this. Firstly, wood chips are by no means solely used for energy purposes. Lamers et al (2012) estimate that less 10% of all wood chips reported in available statistics are traded for energy purposes. The vast majority of international trade in wood chips consists of chips destined for use as raw material for production of pulp & paper and particleboard. Secondly, wood chips do not constitute a homogeneous commodity. Particle size, moisture content and energy density can vary substantially. In combination with the fact that statistics for trade and consumption of wood chips is generally provided in volumetric or weight units, this makes it very difficult to estimate traded volumes in energy units. Thirdly, the physical characteristics of wood that is eventually combusted in the form of chips, might very well change across the supply chain, e.g. if wood used for energy is transported in the form of roundwood and chipped at the site of combustion (Olsson et al. 2012; Lamers et al., 2012).

Regardless of these limitations in terms of data availability, it is clear that wood chips constitute an important source of energy, not least in the Nordic region. However, wood chips have a significantly lower energy density (about 3 GJ/m^3) compared to wood pellets (approximately 11 GJ/m^3). This leads to difficulties in making transportation of wood chips economically viable over longer distances and hence wood chip markets tend to be geographically smaller than those for wood pellets (Alakangas et al. 2007)[4].

[4] Although it should be noted that Japan for a long time has been importing wood chips for its pulp & paper industry (Iwai 2002).

2.3.6 Charcoal

Charcoal is an often overlooked but very important source of energy in many parts of the world, in particular in underdeveloped countries. This is especially the case in urban regions, where the relatively clean combustion of charcoal makes it suitable as cooking fuel[5]. With the ongoing process of rapid urbanization and the unavailability or high costs of electricity, charcoal use is likely to continue to grow (Schure et al. 2013). The consequence is a substantial and growing rural-urban trade.

However, there is very little reliable market data regarding production, consumption and international trade in charcoal, as a result of the "*clandestine nature of production, poor regulation and informality of the sector*"(Mwampamba et al. 2013, p.78). In fact, even discerning trends in market developments from available charcoal market statistics can be difficult. For example, according to data from the International Energy Agency, charcoal production in Colombia decreased from slightly more than 700 000 tons to less than 500 000 tons in the time period 2003-2006, after which production rapidly increased to more than 1 million tons in 2007. According to FAO data however, Colombian charcoal production remained basically flat at about 500 000 tons from 2003 to 2010 (Mwampamba et al. 2013).

The country with the largest charcoal market in the world is Brazil, with approximately 15% of total global consumption according to FAO data, but Brazil is also atypical in the sense that the majority of its charcoal consumption takes place in large-scale industrial applications. In contrast, the vast majority of charcoal consumption in Sub-Saharan Africa is for domestic cooking purposes (Bailis et al. 2013).

2.3.7 Waste-to-energy

Similar to bioenergy markets, waste management has predominantly been a local issue, where decisions by and large are taken and implemented on a municipal or city level (Bogner et al. 2007). This has changed in recent years, partly as a result of legislation (e.g. European Parliament and Council of the European Union 2008) aiming at reducing waste generation and make more efficient use of waste. This process has been especially prevalent in European management of combustible waste. The *waste hierarchy* (see Figure 2) presents a framework of how to make the most efficient use of resources. The aim is to move towards options higher up in the hierarchy. One such strategy that is being widely implemented in Europe is the shift from landfilling to combustion with energy recovery.

[5] Combustion of charcoal in traditional stoves can however still result in significant emissions of harmful pollutants (Zulu and Richardson 2013).

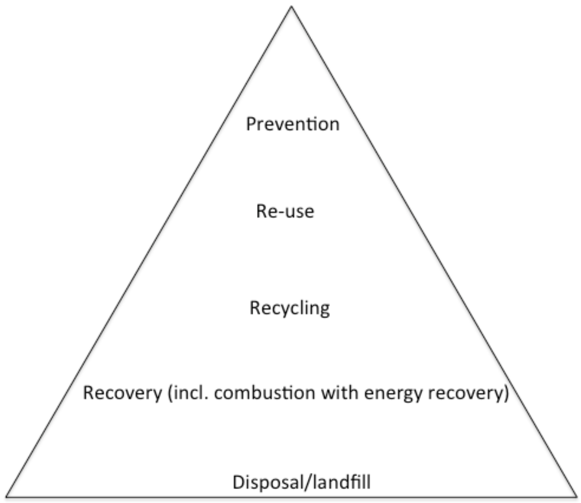

Figure 2. The waste hierarchy.

Waste combusted for energy in the EU is made up by approximately 50-60%[6] renewable material, i.e. different forms of biomass-derived waste (EurObserver 2012; Swedish Energy Agency 2013), although this share can vary depending on the actual composition of the waste in a given location. In Europe[7], about 90 million tonnes of waste was combusted with energy recovery in 2010 (Eurostat 2013c), generating more than 700 PJ of energy. The share between renewable and non-renewable waste was almost exactly 50% each (Eurostat 2013b).

[6] The figure 50-60% is based on energy content.

[7] EU-28 + Iceland, Norway, Former Yugoslav Republic of Macedonia, Serbia and Turkey

3 Bioenergy in the Nordic region

3.1 The role of bioenergy in the Nordic energy mix

The Nordic countries constitute a pioneering region in terms of utilization of renewable energy (Thorsteinsson and Björnsson 2012). When it comes to bioenergy, the picture is a bit more mixed. Whereas renewable energy in Denmark, Finland and Sweden is dominated by bioenergy, it plays only a minor role in Norway and Iceland (see Figure 3).

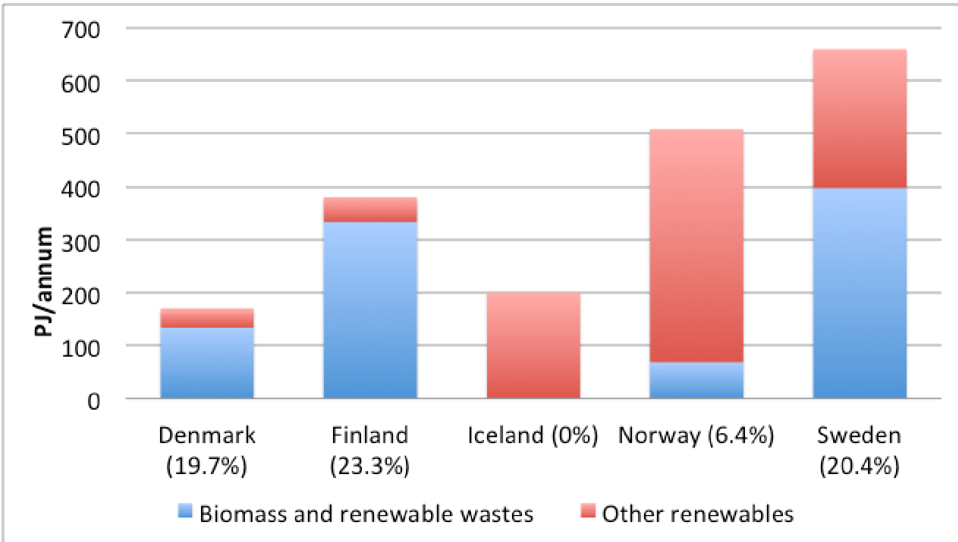

Figure 3. Gross inland consumption of renewable energy in the Nordic countries in 2011. Next to country names are the percentage of biomass & waste in energy supply (Data sources: Eurostat & National Energy Authority of Iceland. Note: Icelandic data is for primary energy supply)

The prevalence of forestry and forest industries in Finland and Sweden are key components in explaining the high level of bioenergy in the two countries, together with ambitious policy measures promoting the use of biomass for energy purposes. Such policies were first instigated in both countries as a response to the oil crises of the 1970's, with the prime objective to reduce dependence on imported oil (Björheden 2006; Hakkila 2006). Denmark's rationale for promotion of bioenergy was also based on experiences from the oil crises, but differing circumstances led to different approaches to the problem. Denmark initially focused heavily on energy efficiency measures and exploitation of the country's North Sea oil & gas resources, but also on support for renewables in the form of wind power as well as heat and electricity from biomass (Lund 2010). Another important factor for end-use market development for biomass in Denmark as well as Finland and Sweden has been the wide dissemination of district heating, which has enabled large-scale conversion from fossil energy to biomass-based fuels.

Bioenergy development has been slow in both Norway and Iceland. A key reason in Iceland is that the country only has very small domestic biomass resources. Furthermore, both Iceland and Norway are awash with other forms of energy: Iceland has large resources of geothermal energy as well as a substantial hydropower production. Norway is one of the world's largest oil exporters in addition to having a very large hydropower sector. In Norway, the large supply of low-cost hydroelectricity has led to low electricity prices to the point where domestic heating is dominated by electricity, thus reducing the competitiveness of other forms of heating such as bioenergy (Trømborg 2011). District heating systems are for example quite rare in Norway, especially relative to its importance in the other Nordic countries (Clarke et al. 2011).

3.2 Bioenergy trade in the Nordic countries

Among the Nordic countries, Denmark, Finland and Sweden all use significant amounts of **bioethanol**. All three rely to a large degree on imports for their supply, although roughly half the Swedish market is supplied by domestic production. As for the origin of the imports, lack of comprehensive statistics makes it difficult to give a reliable overview of this.

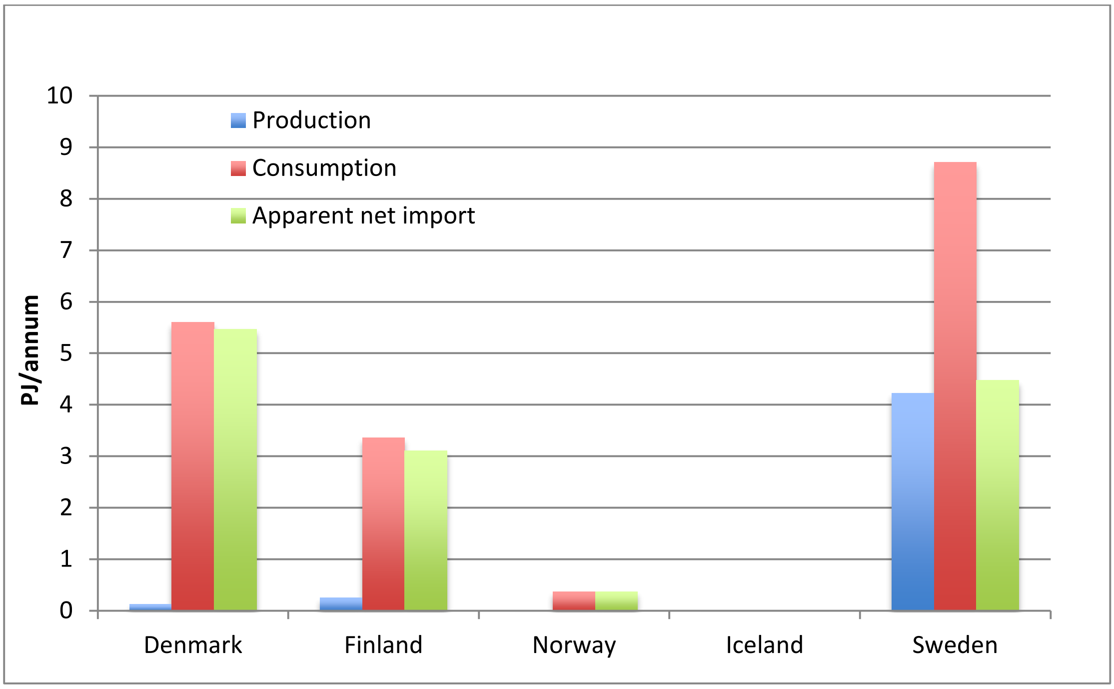

Figure 4. Market data for bioethanol in the five Nordic countries in 2011. Apparent net import is defined as consumption minus production. Data source: US EIA (2013)

For **biodiesel**, the situation is somewhat different to that in bioethanol markets. As with bioethanol, the largest biodiesel market in the Nordic countries can be found in Sweden, which is both the largest producer and consumer of biodiesel among the five countries. There is no import of biodiesel to Sweden, although almost all raw material for biodiesel production is imported from countries such as Denmark (24%), Lithuania (22%), Ukraine (21%) and Germany (13%) (Swedish Energy Agency 2012a). A similar situation can be seen in Norway, where biodiesel production is based on imported rapeseed oil (Trømborg 2011). Denmark imports substantial volumes of biodiesel, but exports are larger, making the country as a whole a net exporter. The Danish export is a result of unfavorable tax conditions in the country compared to export markets (Nikolaisen 2012). Finland is also a net exporter, with about half the domestic production of biodiesel consumed outside the country. Here as well, production is largely based on imported raw materials, mainly palm oil but also different forms of waste fats (Heinimö and Alakangas 2011; Neste Oil 2013).

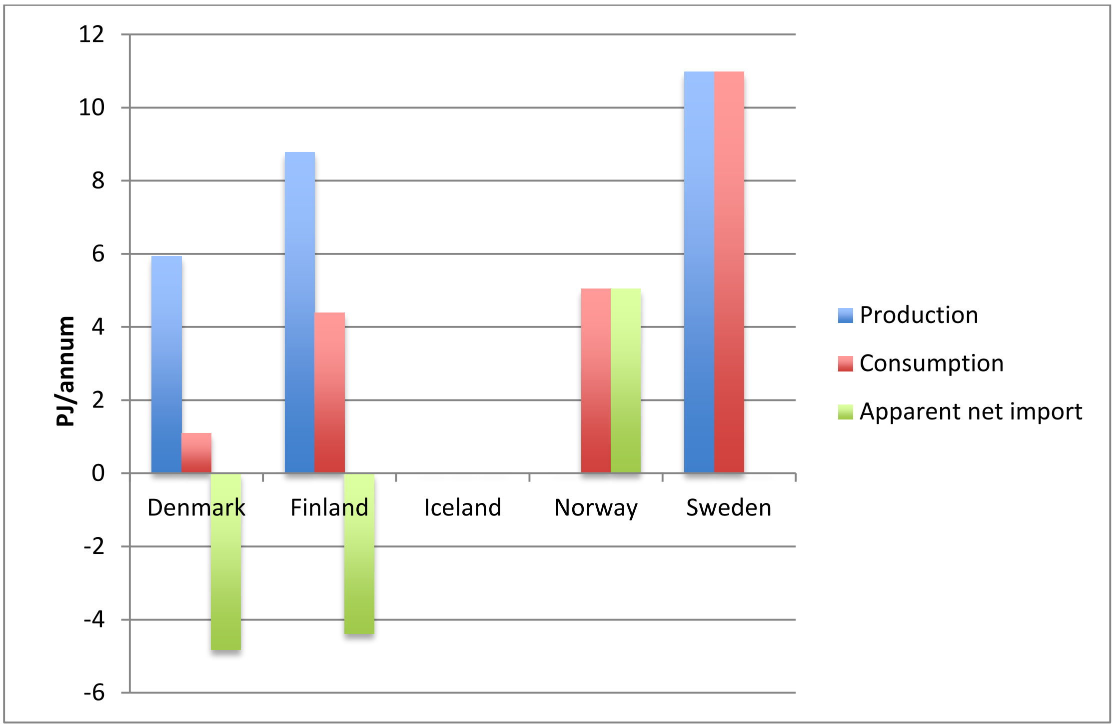

Figure 5. Nordic biodiesel market data for 2011. Apparent net imports are defined as consumption minus production. Data source: US EIA (2013)

Among the five Nordic countries, Denmark and Sweden are the dominating users and importers of **wood pellets**. In 2012, Denmark imported about 2 million tonnes (roughly 34 PJ) and Sweden approximately 665 000 tonnes (≈11 PJ). Both countries primarily import from countries around the Baltic Sea with Estonia, Latvia, Russia and Germany as key suppliers. For Denmark, Portugal is also an important supplier whereas the US and Canada – which both export large amounts to the UK, Netherlands and Belgium – only contributed with marginal quantities to the Nordic region. Sweden and Finland also export wood pellets to Denmark (Eurostat 2013a). Norway has only a very small domestic market, although there have been plans to initiate export-oriented wood pellet production based on imported raw material (Trømborg 2011)[8]. An overview of international wood pellet trade in the Nordic countries can be seen in Figure 6.

[8] In 2010 a pellet production facility with a capacity of 450 000 tonnes/year was established on the west coast of Norway. Following severe problems related to market conditions and technical production issues, the plant was closed in early 2013 (Biowood Norway 2013).

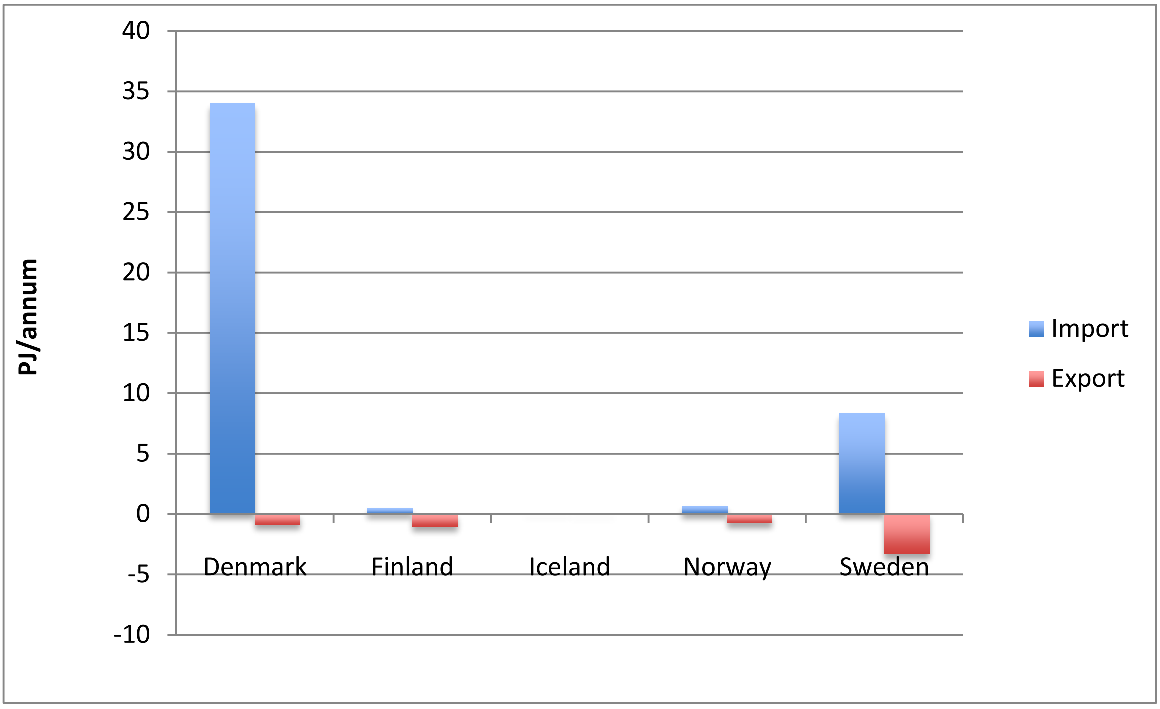

Figure 6. International trade in wood pellets in the Nordic countries in 2012. Data source: UN Comtrade

As was discussed in section 2.3.5, the amounts and patterns of trade in **wood chips** for energy purposes are for several reasons difficult to estimate. It is clear however that this is an important phenomenon in the Nordic countries, especially Denmark and Sweden. In Denmark, about 25% of domestic consumption came from imports in 2012, mainly from countries around the Baltic Sea (Dansk Skovforening et al. 2013) but also from Ghana in the form of wood chips made from discarded rubber trees (Gibson 2011). Sweden also imports significant amounts of wood chips, again mainly from other countries in the Baltic Sea region and predominantly by ship (Olsson et al. 2012). There are however also trade flows of wood chips from Norway to Western Sweden via train (Valente et al. 2012). Concurrent with these flows of wood chips explicitly destined for energy purposes, there is also an *indirect* trade in woody biomass that will eventually be used as energy. This is a consequence of the large trade in wood used for raw material in pulp & paper production, especially in Finland and Sweden. During the Kraft pulp production process, parts of the wood is used to produce process heat within the pulp mill (Heinimö and Alakangas 2011).

Landfills are increasingly being phased out as a waste management option in much of Europe, including the Nordic countries. This means that there is increasing demand for alternatives higher up the waste hierarchy, such as **waste-to-energy**. Between the five Nordic countries, there are substantial differences in management of municipal solid waste (MSW), see Figure 7.

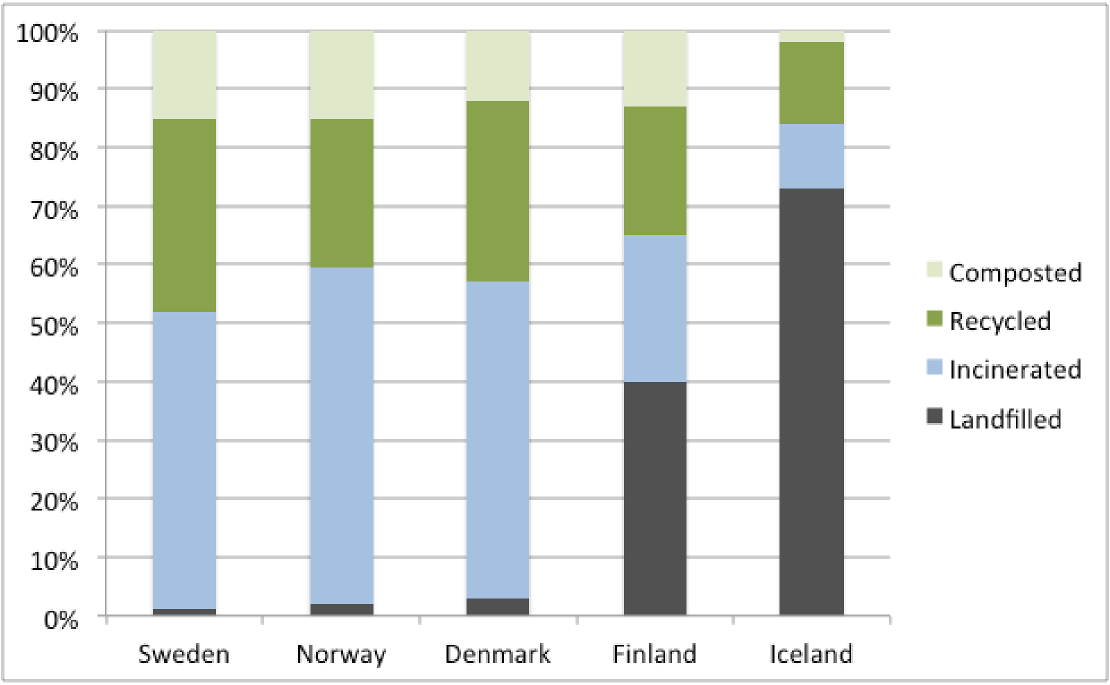

Figure 7. Treatment of municipal solid waste (MSW) in the Nordic countries. Data source: Eurostat

In Denmark, Norway and Sweden, waste combustion with energy recovery is an established part of energy supply in many urban areas, especially in district heating systems, see Figure 8. In 2012, waste incineration provided more than 40% of fuel input in district heating in Norway, about 18% in Denmark and Sweden and less than 2% in Finland (Danish Energy Agency 2013; Finnish Energy Industries 2013; Statistics Norway 2013; Swedish District Heating Association 2013).

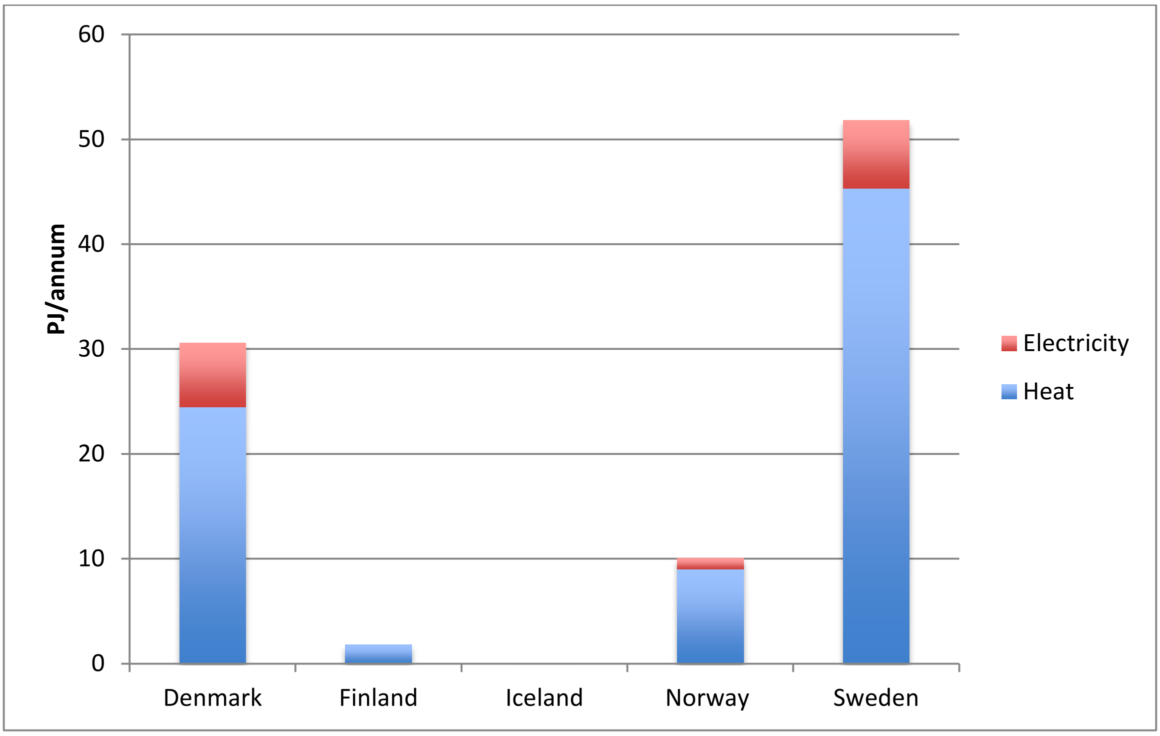

Figure 8. Production of heat & electricity from waste in 2010. Data source: CEWEP (2012)

There is increasing international trade in combustible waste. In the Nordic countries, there are significant amounts of trade from Norway to Sweden, which provides some explanation to the data seen in Figure 9.

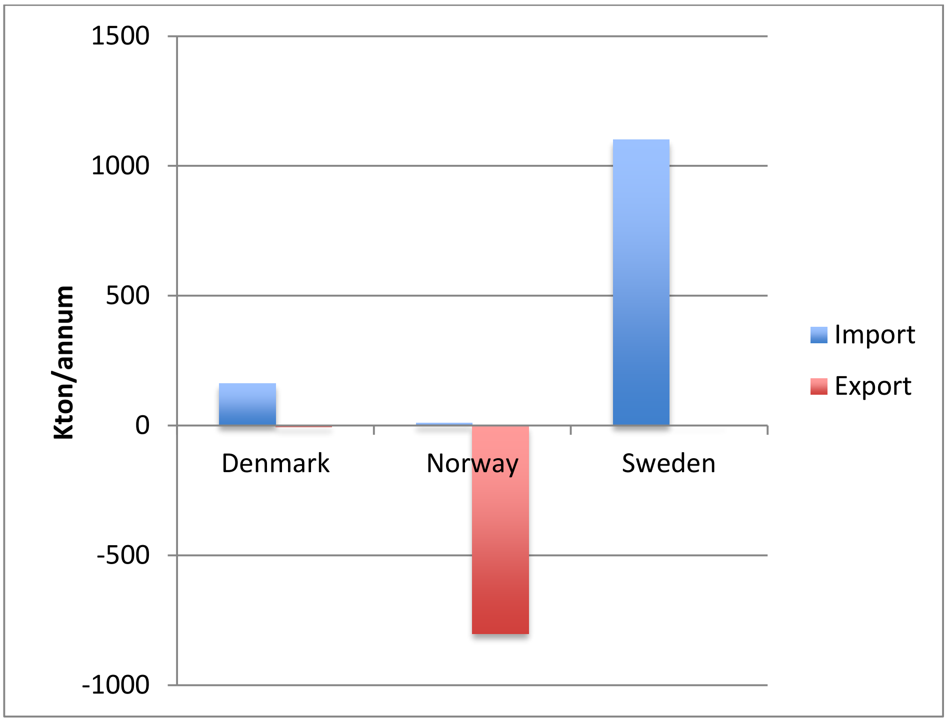

Figure 9. International trade in combustible waste in 2010 (Norway & Sweden) and 2011 (Denmark). No data was found for Finland and Iceland. Data sources: (Danish EPA 2013; Norwegian Climate and Pollution Agency/Environment.no 2011; Swedish EPA 2012)

Apart from Norway, Sweden also imports from the UK, the Netherlands and Ireland (Avfall Sverige 2013). Danish imports are primarily from the UK and Germany (Wittrup 2013).

3.3 The role of bioenergy in the climate policies of the Nordic countries

Up until 2020, the main determinant for developments in markets for renewable energy, including bioenergy, is the framework established by the European Union in the so-called Renewable Energy Directive (2009/28/EC). The EU aims to increase the share of renewable energy in the Community as a whole to 20%. In order to reach these goals, each member state has been assigned an individual goal that is to be reached in order for the EU as a whole to achieve the 20% target (Council of the European Union 2009). Three of the Nordic countries – Denmark, Finland and Sweden – are members of the European Union and as such have received individual national goals for 2020. Norway and Iceland are not part of the EU but of the European Economic Area (EEA) and are hence participating in the RED process as of the 2011 incorporation of the RED into the EEA agreement (Quaderer and Rübig 2012; Roggenkamp et al. 2012). In other words, both Iceland and Norway also have national goals to be fulfilled until 2020. For an overview of the goals and current progress of the RED goals in the five Nordic countries, see Figure 10.

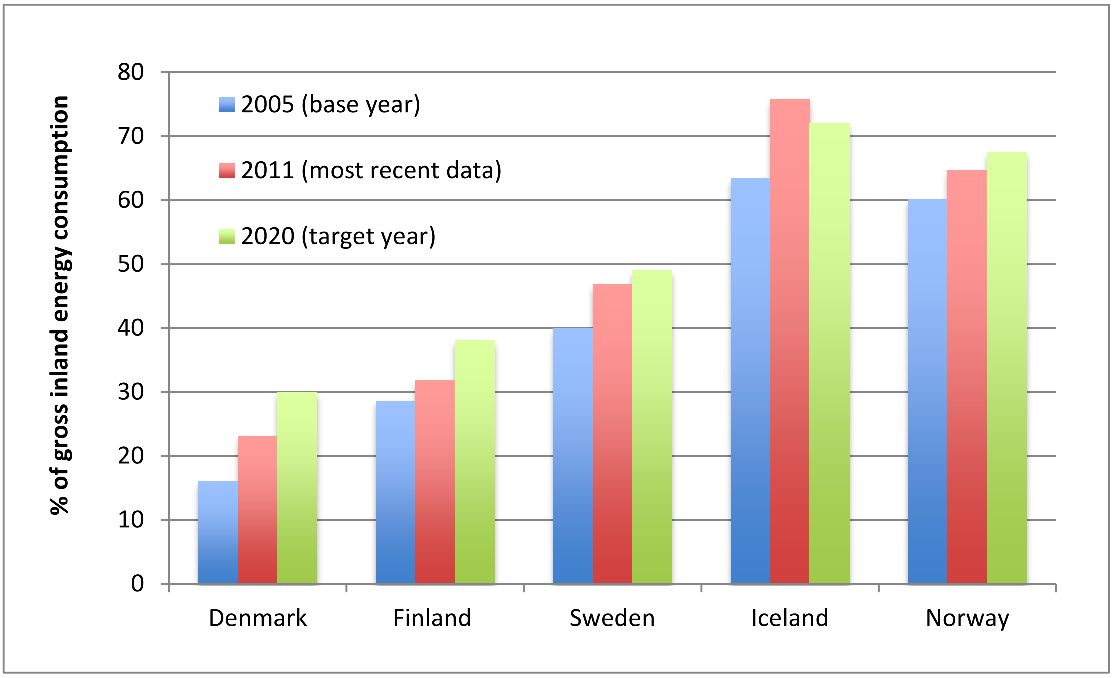

Figure 10. The base point, current status and goals for the share of renewable energy in the energy systems of the five Nordic countries (Data source: Eurostat & Icelandic Ministry of Industries and Innovation).

For comparison, in the European Union as a whole, the share of renewable energy was 13% in 2011. All the Nordic countries have a higher share than this and are making significant progress towards reaching their goals for 2020. As can be seen in Figure 10, Iceland has already surpassed its goal.

All countries adhering to the RED are mandated to present their respective strategies for how to reach the 2020 goals in National Renewable Energy Action Plans (NREAPs). In the EU-27 as a whole, the contribution of bioenergy to the total energy consumption is expected to more than double between 2010 and 2020 (AEBIOM 2012). The Nordic countries are also expected to see an increase in the use of bioenergy, although the increase will be more moderate, approximately 30% (see Figure 11). This relatively slow growth of bioenergy in the Nordic countries is mainly a result of the already high share of biomass-based fuels in the region's energy systems.

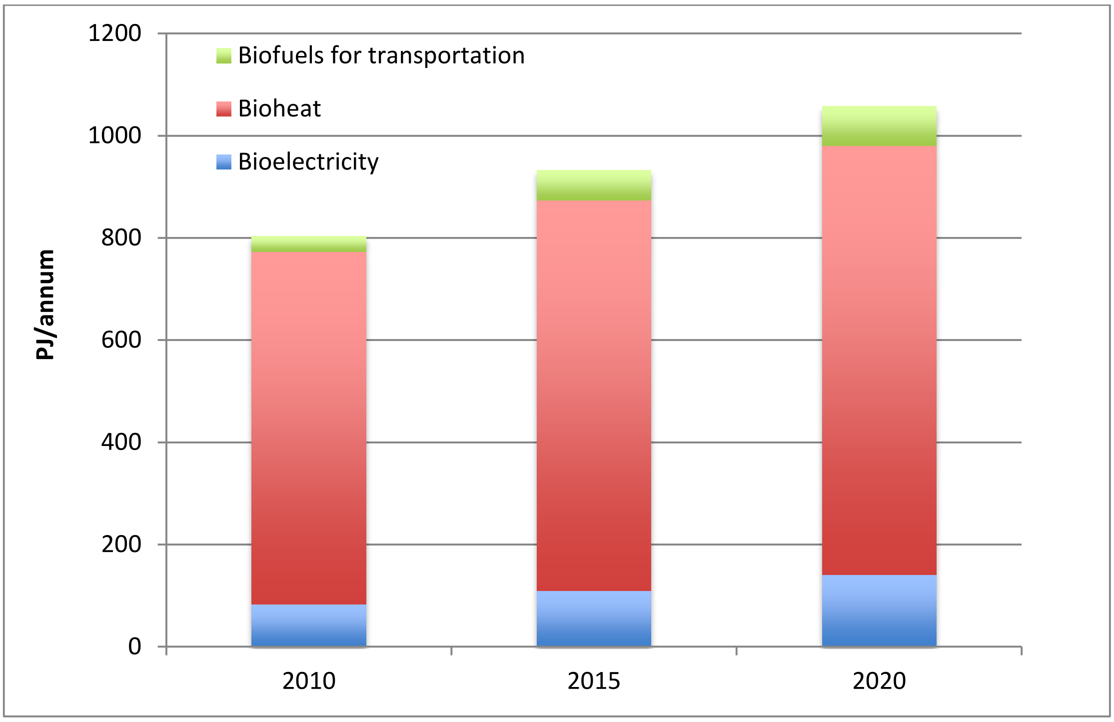

Figure 11. Expected increase in bioenergy consumption in the Nordic countries 2010-2020 (Data sources: Iceland's Ministry of Industries and Innovation 2012; Norway Ministry of Petroleum and Energy 2012; AEBIOM 2012).

In addition to the targets regarding the total energy mix of each country, there is also a specific target concerning the share of renewables in the transportation sector. This mandates that all RED signatories are to have a national share of 10% renewable energy in the transportation sector by 2020 (Council of the European Union 2009). Here, there are significant differences between the Nordic countries in terms of their progress towards the goal. The share of renewables in transportation in the five Nordic countries in 2011 can be seen in Figure 12. Sweden's high share is due in part to the fact that it began experimenting with alternative fuel vehicles already in the 1980s on the basis of policies aimed at regional air quality improvements, which was in addition to the national energy security rationale that was becoming common in many countries (Eklöf et al. 2012).

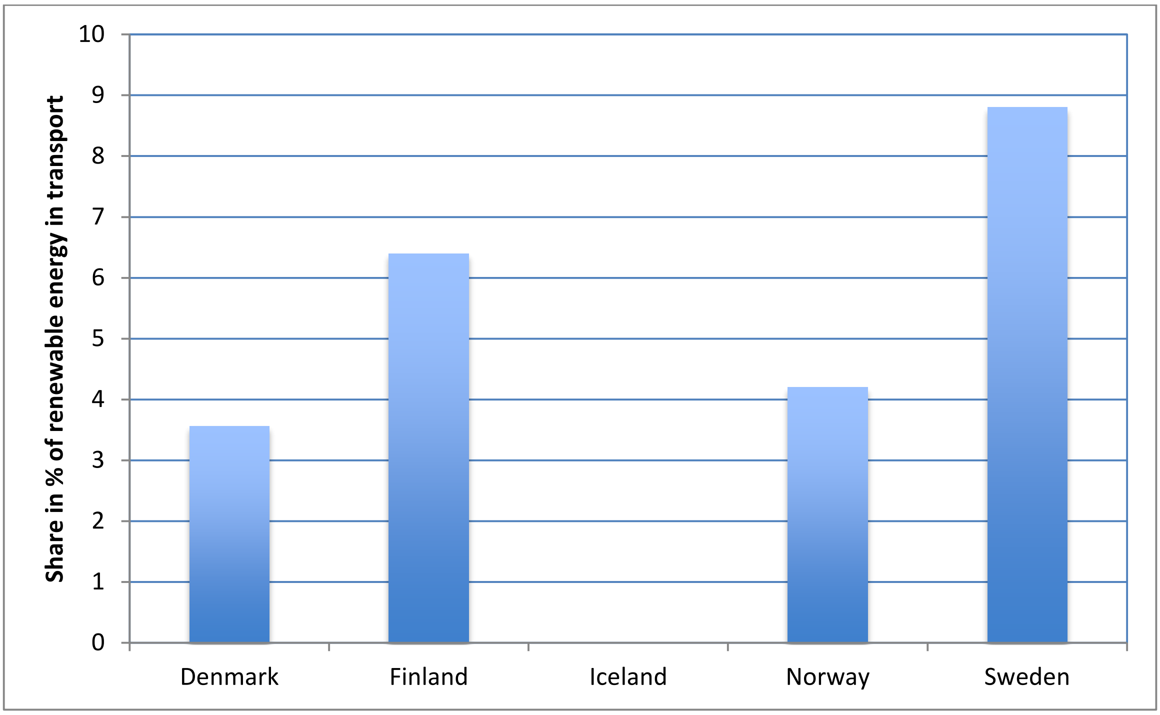

Figure 12. Share of renewable energy in the transport sector in the Nordic countries in 2011. ((Data sources: Eurostat & Second National Progress Reports on the Promotion and Use of Energy from Renewable Sources). No data was found for Iceland.)

In the National Renewable Energy Action Plans (NREAPs), the respective countries are asked to estimate the amount of transportation biofuels that will be produced domestically and how much that will be imported. Here it is informative to note some distinct differences in the strategies of the five Nordic countries. Whereas Norway and Denmark will fully rely on imports, Finland and Iceland aim for 100% domestic production. Sweden aims to import 60% of the national demand for bioethanol whereas all biodiesel is expected to be produced domestically (Beurskens et al. 2011; Norway Ministry of Petroleum and Energy 2012; Iceland's Ministry of Industries and Innovation 2012). In response to questions from the European Commissions regarding the specifics of the biofuel imports in the NREAPs, Sweden states that although all biodiesel is expected to be produced domestically, imports of raw material for biodiesel production will likely be necessary (Swedish Government 2011).

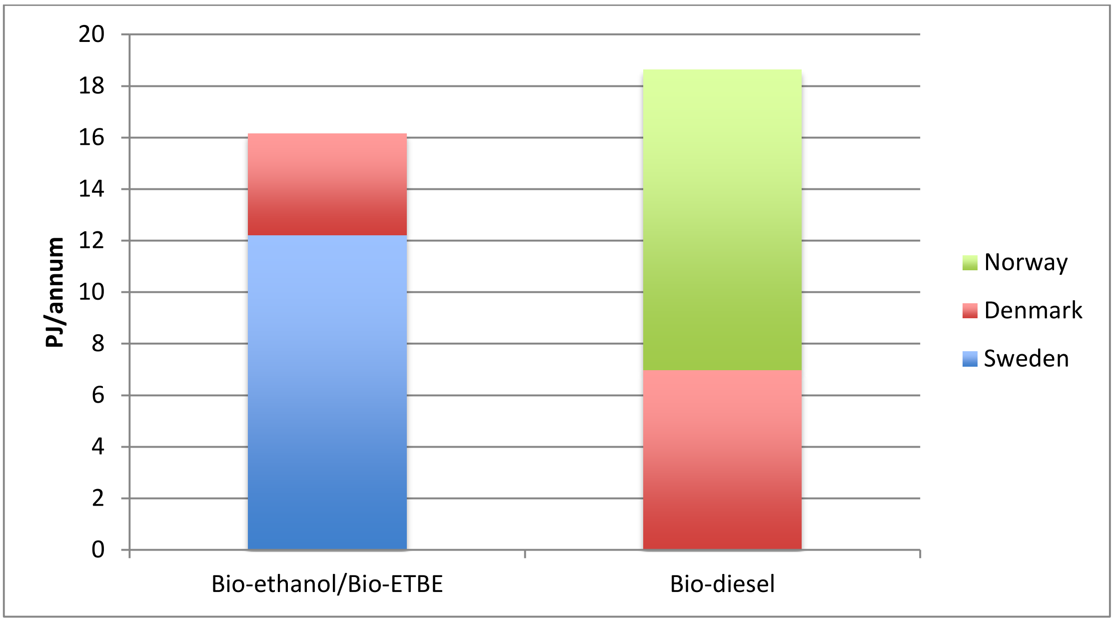

Figure 13. Planned imports of transportation biofuels to the Nordic countries in 2020 according to the NREAPs. ETBE (Ethyl tert-butyl ether) is an ethanol-based petrol additive. (Data sources: Beurskens et al. 2011; Norway Ministry of Petroleum and Energy 2012)

An additional issue worth noting is the recently proposed changes to the RED concerning the share of renewable energy in the transportation sector. According to an analysis conducted by Bowyer (2010) of the NREAPs of the EU countries, 92% of the biofuels used in the transport sector would consist of conventional crop-based biofuels. In total this would amount to 8.8% of total transportation energy use in the EU. However, in July 2013, the European Parliament's environment committee voted to limit crop-based biofuels to 6% of total transportation use (Euractiv.com 2013). If this becomes part of EU legislation, it will clearly entail that changes have to be made in the 2020 strategies of most European countries.

4 Inter-relationships between mitigation and adaptation

4.1 Mitigation of, and adaptation to, climate change: overview

Two general approaches have been distinguished as means by which society can confront climate change risk. *Mitigation*, which puts focus on minimizing climate change by reducing emissions of greenhouse gases and enhancing carbon sinks, and *adaptation*, which primarily entails reducing vulnerability to climate change (Klein et al. 2005; Schipper 2006).

Up until the beginning of the 2000's, climate change policy discussions were heavily dominated by a focus on mitigation. However, it has become increasingly clear that regardless of current and future mitigation efforts, climate change will occur and adaptation is thus necessary (Klein et al. 2005). The growing focus on adaptation is exacerbated by the absence of a binding post-Kyoto international agreement on the limitation of greenhouse-gas emissions (Dow et al. 2013). However, it is important to note that an all-out shift of emphasis from mitigation to adaptation is not a viable route as this would imply such a significant level of climate change that adaptation measures would become exceedingly costly or impossible to achieve.

Traditionally, there has been much focus on the inherently different characteristics of adaptation and mitigation. To a certain extent, this view has merit. Adaptation measures tend to be local or regional in their geographical scope and are effective in the near term by immediately increasing resilience to climate change effects (Klein et al. 2007; Moser 2012). Mitigation efforts have on the other hand predominantly consisted of long-tem endeavors, aimed at minimizing climate change by reducing emissions of greenhouse gases into the atmosphere. As a result of time lags in the global climate system, this is to a large extent a process that is acting over time periods of decades or more. Furthermore, whereas the benefits from mitigation efforts are shared widely, adaptation efforts tend to be beneficial primarily at the local level. There are also notable differences in terms of the actors involved in carrying out mitigation and adaptation. Whereas the bulk of mitigation measures have traditionally been designed and implemented on levels of government or corporations in a limited number of sectors, adaptation takes place at all levels in society and by a wide variety of actors (Klein et al. 2007).

However, recent research emphasizes that the conceptual discrepancy between mitigation and adaptation may be less severe than was previously envisioned. Firstly, the globalization of the world economy in the form of intercontinental supply chains means that local adaptation efforts can have positive effects on a global level (Benzie et al. 2013). In addition, there is growing awareness of the importance of short-lived climate forcers. Mitigation efforts focused on black carbon and ozone precursors are interesting in that not only can they can reduce near-term warming, in addition *"…most substantial benefits will be felt immediately in or close to the regions where action is taken to reduce emissions*." (UNEP and WMO 2011, p.3) which contradicts the view of mitigation as a strategy without near-term benefits for the very actors involved in practical implementation. Finally, the absence of a globally binding agreement aimed at emission reductions has also led to a development where individual businesses and consumers are increasingly viewed as important actors when it comes to driving mitigation (Sheth et al. 2010).

To a growing extent, adaptation and mitigation are being seen as complementary strategies. Here as well, there is a certain conceptual difference where adaptation is a form of direct damage prevention and mitigation an indirect strategy (Verheyen 2005; Klein et al. 2007), but the final objectives of the two strategies are the same: to prevent damages from climate change. Discussion on the two strategies is sometimes framed as a dilemma of choosing one over the other (Tol 2005) but there are plenty of conceivable policy measures where mitigation and adaptation can be combined and produce synergy effects. This could not only reduce the cost of policy implementation but also produce more sustainable and resilient systems. It can be argued that any coherent strategy aiming at minimizing the risks of catastrophic climate change should thus consist of a combination of mitigation and adaptation efforts (Klein et al. 2005; Klein et al. 2007).

It is nevertheless important to emphasize that combining mitigation and adaptation in actual implementation can be very challenging, and there is a risk of adaptation measures working against mitigation efforts[9] or vice versa (Moser 2012). The inherent gains to be made by pursuing mitigation and adaptation in tandem have therefore been questioned (Klein et al. 2005) but more recent research suggests that there are indeed plenty of potential substantial synergy effects in combining mitigation and adaptation (Klein and Juhola 2013).

As will be discussed in further detail below, bioenergy systems have been put forward as examples of implementations where the synergies can be substantial (Juhola et al. 2012). This is connected mainly to the possibilities that bioenergy can help alleviate problems related to the temporal discrepancy between the long-term gains from mitigations and the more immediate benefits from adaptation.

In this context it is also worth mentioning a recently proposed perspective on adaptation, one that includes not only adaptation to climate *change*, but to the consequences of climate *policy* as well (Klein and Juhola 2013), i.e. *adaptation to mitigation*. It has been recognized that implementation of climate policy can itself create positive and negative environmental, social and economical effects that need to be taken into account. Perhaps the most publicly recognized example of the complex interactions that can arise is related to bioenergy trade and the so-called “food vs. fuel” dilemma. This centers around the impact of increased demand for bioenergy on food markets and the consequences that this might have for global food availability and malnutrition, i.e., possibly adverse effects of mitigation policies (e.g. Rosillo-Calle and Johnson 2010; Bryngelsson et al. 2012).

4.2 Adaptation-mitigation inter-relationships in Nordic policy

In order to review the level of interaction between the two strategies in practice, it can be informative to review some relevant policy documents in the Nordic countries. So far, only Denmark and Finland have published formal National Adaptation Strategies, and hence other documents are analyzed for the remaining three countries. The selection of the latter is based on the comprehensive review of Nordic adaptation policies found in Klein & Juhola (2013).

[9] A commonly cited example is how a warmer climate could increase the need for air-conditioning (an adaptation measure) which would increase demand for electricity, which could lead to increased GHG emissions.

Denmark published its National Adaptation Strategy (The Danish Government 2008) in 2008, and although it indirectly includes elements on mitigation-adaptation interactions (in a discussion of the impact of climate change on renewable energy production), there is no clear appreciation of the potential synergies or conflicts between the two.

Finland was a pioneer in terms of governmental involvement in adaptation with the publication of its 2005 National Adaptation Strategy (NAS) (Marttila et al. 2005). A 2009 evaluation (Ministry of Agriculture and Forestry 2009) of the strategy complimented the progress that was being made in terms of implementation of the NAS, but pointed out that *"[t]he next Adaptation Strategy should also deal with the synergies and potential conflicting objectives of the mitigation and adaptation measures*"(Ministry of Agriculture and Forestry 2009, p.17). The Finnish NAS is currently (2011-2013) undergoing a new review process.

The key climate change policy document in Iceland is the 2007 Climate Change Strategy (Ministry for the Environment 2007), which combines policy strategy on mitigation and adaptation. This suggests an inherent appreciation of the inter-relationships between the two approaches, but the main focus of the Strategy is on mitigation aspects. Indirectly however, there are discussions that touch upon mitigation-adaptation inter-relationships, e.g. by highlighting the consequences of increased transport of oil and gas in the Arctic.

In 2008, a document presenting national key adaptation issues was published by the Norwegian Directorate for Civil Protection and Emergency Planning (2008). Without explicitly discussing the inter-relationships between adaptation and mitigation, the issue is touched upon in several occasions, especially in relation to climate change impacts on the energy sector. For example, the strategy acknowledges the expected increased supply of energy from both hydropower and bioenergy.

Sweden has thus far not published a formal National Adaptation Strategy (Glaas 2013) although adaptation is covered to a substantial degree in the 2009 government bill on climate and energy policy (Swedish Government 2009). The integration of mitigation and adaptation could – as in the Icelandic case – be seen as a sign of recognition of the role of adaptation-mitigation inter-relationships. Although a conceptual discussion of the issue is absent from the bill, it does give examples of mitigation-adaption inter-relationships, including impacts of climate change on supply systems of forest-based bioenergy.

5 Effects of climate change on bioenergy markets

As was noted in section 2, bioenergy markets are very complex phenomena as a result primarily of their interconnections with many other economic sectors. The consequence is that it is difficult to predict all possible effects of climate change on bioenergy markets and bioenergy trade. This is especially true if one tries to forecast the spillover effects into bioenergy markets from climate change on adjacent sectors. Hence, in the following, the ambition is to focus on more direct consequences of climate change on bioenergy markets. The analysis is divided according to the different parts of the bioenergy supply chain, starting with the supply side (cultivation etc.), moving on to climate impact on the demand side of the market and then finally the link between production and consumption, i.e. distribution and logistics.

5.1 Impact of climate change on bioenergy supply

5.1.1 General impacts on the supply of bioenergy from agriculture and forestry

Biomass used for energy purposes is to a dominating extent produced in agricultural or silvicultural systems, both of which are inherently weather- and climate dependent. Hence, bioenergy supply will be affected by climate change as forestry and agriculture are among the sectors that will be most affected by a changing climate (Adger et al. 2007).

New fluctuations in precipitation patterns and temperatures will have effects on the production of all forms of biomass, be it for energy purposes, for food or for production of pulp & paper. These impacts can be direct or indirect. Direct impacts include climate changes that make a particular region outright unsuitable for certain crops, e.g., as a result of insufficient annual amounts of rainfall or increased incidence of frosts or droughts, whereas indirect impacts include e.g. improved conditions for pests as a result of a warmer climate (IPCC 2012). For an example of how the latter can impact bioenergy markets, see Example Box 1.

Example box 1: ***Warm Canadian winters, insect-damaged trees and wood pellet markets***

An example of the damages from indirect climate impact can currently be observed in in British Columbia (BC) in Western Canada. Here, periodical outbreaks of infestation by the Mountain Pine Beetle (*Dendroctonus ponderosae*) have historically occurred from time to time. However, the life cycle of the beetle is quite sensitive to temperatures which means that the occasional very cold winters in BC has traditionally kept a lid on the geographical and temporal extent of the infestations. However, in recent decades, the cold winters needed to halt MPB expansion have become increasingly rare (c.f. Williams and Liebhold 2002) which has resulted in a currently ongoing infestation of previously unseen proportions. The result is an immense amount of damage to the standing timber, increased risk of wildfires, massive capital destruction as well as a large net source of emissions of carbon into the atmosphere. In terms of climate impact, there are also albedo-related effects from the infestation that increase the speed of snow melt. In other words, this means that the mountain pine beetle infestations are having a feedback effect, in effect enhancing the climate change that has contributed to the current situation (Kurz et al. 2008). As a means to take care of and make use of the massive amounts of damaged trees, and thereby possibly reduce the risk of wildfire, wood pellet production based on MPB-damaged wood has been proposed as a productive approach. The economic viability of this endeavor has been questioned, as lack of roads and other infrastructure could make harvest costs excessive (Johansson 2012; Niquidet et al. 2012). Nevertheless, there is here the potential of substantial net carbon savings, especially if the wood pellets are used to replace coal (Lamers et al. 2013).

Tropical regions will be most hardly hit when it comes to reduced crop yields from climate change, e.g., as a result of problems with water supply. It is worth noting that problems can be expected in both irrigated and rainfed fields (HEC/CABI 2010). Additionally, flooding can also impact production, as has been displayed in rainfall-induced flood damages to planting operations in corn-producing regions of the US (US DOE 2013)[10].

Temperature increases could also prove highly detrimental, although this depends to a degree on the level of warming, as modest temperature increases could lead to higher crop yields for many grains (Easterling et al. 2007). When it comes to indirect impacts, these could include positive effects such increased productivity as a result of higher CO_2 levels, but also increased prevalence of pest insects and plant pathogens (Ebinger and Vergara 2011; Juroszek and von Tiedemann 2013). Drier climates could also increase the risk of soil erosion, which is the topic of Example box 2.

Example box 2: ***Corn ethanol & soil erosion in the US midwest***

Increased demand for corn, partly for production of bioethanol, has meant that cultivation in the US Midwest is being expanded to fields that are susceptible to erosion (Neuman 2011). This is problematic especially as climate change is likely to lead to an increase in storms that can lead to large and rapid loss of topsoil, something that has had catastrophic consequences in the past. Rapid expansion of farmland and several continuous years of drought were among the main causes of the 1930’s Dust Bowl, which is among the largest environmental disasters in United States history (Montgomery 2007). In addition, there are fears of the depletion of aquifers in corn-producing regions of the US, resulting from excessive use of underground water sources for irrigation of cornfields, as irrigation itself was introduced as a vital part solution to the difficult climatic and soil conditions of the US high plains. More efficient water use is imperative if cultivation of corn, which is a very water-demanding crop, can expand further without the reoccurrence of the conditions that lead to the catastrophic soil erosions of the 1930’s (Brodwin 2013).

5.1.2 Impacts from climate change on bioenergy supply in the Nordic region

The impact of climate change on the supply potential of renewable energy in the Nordic countries is

[10] In the context of market impacts, adaptation to mitigation and the food vs. fuel debate, results from a recent study suggest that climate change can be an even more important factor than increased biofuel demand when it comes to increasing food prices (Lotze-Campen et al. 2014).

expected to be mainly positive. For example, hydropower production is likely to increase, although dams and related infrastructure will have to be adapted to new seasonal patterns in runoff. (Norwegian Water Resources and Energy Directorate 2006; Bergström et al. 2012).

As regards bioenergy production, a warmer climate will increase productive capacity in most forests in the Nordic region. Although it is difficult to estimate the share of increased forest growth that will be available for energy purposes, an increase in the supply of forest-based bioenergy is to be expected (Fenger 2007; Gode et al. 2007; Kellomäki et al. 2012). A similar development can also be expected in agriculture, although extreme weather events can become a larger threat to both agriculture and forestry (IPCC 2012) although this is not necessarily through an increased frequency of extreme events. Warmer winters in the Nordic countries could mean that soils are frozen for shorter time periods of the year. This increases the likelihood that trees fall over when exposed to high winds. Norway spruce (*Picea abies)* is especially vulnerable in this regard and this vulnerability was a contributing reason to the severe effects of hurricane Gudrun on Nordic forests in early 2005. This storm also caused severe disruptions in the supply systems for bioenergy, see Example box 3.

Example box 3: ***Extreme weather event impacts on wood fuel supply systems***

Logging residues, which make up large parts of Finnish and Swedish bioenergy supply, are typically removed as a part of final fellings in order to maximize efficiency. However, this system is rather complex, requires planning and is thus vulnerable to outside disturbances. In the turbulent situation following Hurricane Gudrun (which during a few hours in January 2005 felled trees amounting to an entire annual felling in Sweden) all logging resources were focused on salvaging high-quality timber as quickly as possible in order to prevent damages by insects and fungi. This meant that removal of logging residues was not a priority and between 2004 and 2005, the area from which logging residues were extracted decreased by 60% in Southern Sweden (Swedish Forest Agency 2013). As it turns out, the actual market effects were not as great as might first have been imagined, as the reduced supply of logging residues was to a degree made up by an increase in the supply of sawmill residues and downgraded timber (Olsson 2006; Swedish Energy Agency 2006; Björheden 2007).

In terms of positive developments, climate change is likely to improve conditions for agriculture in the Nordic region in general. A longer growing season and the introduction of new crops would lead to increased overall yields, although this can come with the cost of increased pest problems (Maracchi et al. 2005). In terms of conditions for energy crops in particular, climate change is also likely to lead to improved conditions for cultivation of perennial grasses in the Nordic region. *Miscanthus spp.* is one example of a perennial grass that is currently not ideally suited for the Nordic countries, since it can have trouble overwintering in colder climates (Lewandowski et al. 2003; Swedish Board of Agriculture 2011). High yields are also expected from *Salix spp.*, which to a certain degree is grown for energy purposes especially in Sweden (Oliver et al. 2009).

5.2 Impact of climate change on bioenergy demand

Bioenergy demand will also be affected by climate change, both in ways that are specific to bioenergy but also as an energy source among others. For example, demand for electricity, including bioelectricity is likely to increase in many regions of the world as a result of increased need for cooling. At the same time, other regions will experience lower demand for heating with less severe winter temperatures (US DOE 2013). In this context, it is however important to note that only producing electricity (i.e. without utilization of associated heat production) from biomass-based fuels is not necessarily a very efficient use of biomass as a resource, i.e. other means of producing renewable electricity might be more competitive.

On a global level, it is generally expected that the costs from increased demand for cooling will be larger than the benefits from reduced demand for heating (Adger et al. 2007). In the Nordic context however, the situation is likely to be the opposite, i.e., the gains from reduced demand for heating will be greater than the costs of increased demand for cooling (Swedish Government 2007; Pilli-Sihvola et al. 2010). As could be seen in Figure 11, heating is the most important category in terms of bioenergy consumption in the Nordic region. Climate change is expected to bring about a general warming of the geographical region that includes the Nordic countries. For example, by 2040, annual demand for heating in Swedish buildings is expected to have decreased by 15% (Gode et al. 2007). Bioenergy is also an important part of heat supply in Denmark, Finland and (albeit to a lesser extent) Norway. A general reduction in heat demand will thus also impact bioenergy demand.

As was noted above, demand for air-conditioning and thus electricity is on the other hand likely to increase with a warmer climate (Fenger 2007). Even though this effect is expected to be smaller in the Nordic countries than the reduction heat demand, the effect on electricity markets in the region could still be substantial. As European electricity markets are increasingly being integrated through interconnection of physical infrastructure and institutional reform, the Nordic electricity market – possibly including Iceland (Quaderer and Rübig 2012) – will to a larger degree interact with electricity markets in other parts of Europe. Depending on the progress of integration, increasing energy demand for cooling in Southern Europe could spill over into Nordic electricity markets (Aaheim (ed.) 2009).

Another possible effect on bioenergy demand for heating could come from impacts of climate change on the criteria that consumers use to choose residential heating systems. In detached houses in the Nordic region – especially Sweden and Denmark – homeowners often choose between bioheat[11] and different kinds of heat pumps. In recent years, the market share of heat pumps has been growing. A problem with heat pumps is that their efficiency is reduced with very cold temperatures (Swedish Energy Markets Inspectorate 2012). With warmer winter temperatures in the Nordic countries, this drawback of heat pumps becomes less important. Furthermore, heat pumps can also function in reverse, i.e. providing cooling instead of heating. If climate change leads to warmer summer temperatures in the Nordic region, this could be an additional advantage for heat

[11] This can be in the form of indirect bioheat (in the form of bioenergy-based district heating) or direct bioheat (boilers or stoves fueled with firewood or pellets).

pumps relative to bioenergy-based heating solutions. Consequentially, this might be another factor that impacts the demand for bioenergy.

5.3 Impact of climate change on distribution and logistics in bioenergy markets

An important component of bioenergy markets that tends to be overlooked and that will also be affected by climate change, is logistics. The relatively low energy density of solid biomass fuels in particular means that fuel transportation becomes a crucial part especially of systems based on solid biomass-based fuels. The problem can take many different forms, from the arduous task of procuring firewood facing rural poor in developing countries to the complex logistics systems necessary to provide European power stations with wood chips and wood pellets.

The switch from fossil fuels to bioenergy comes at a cost of increasingly complicated logistics, especially with district heating plants and power stations located in urban areas with limited space available for on-site fuel storage. Fuel logistics tends to be based on continuous fuel supply either via fuel terminals or directly from external suppliers (Sycon 1999; The Swedish Association of Road Transport Companies 2011). This increased reliance on fuel transportation is an important component to take into account when assessing the adaptive capacities of bioenergy systems. However, there is not very much compiled knowledge about the vulnerability of these supply chains and many issues are yet not researched to a satisfactory level (Swedish Energy Agency 2009).

The vulnerability of fossil fuel logistics to weather-related disturbances in recent years has on the other hand been well documented, with both droughts and floods affecting coal barges in the Mississippi river system (US DOE 2013). Again, as a result of the lower energy densities and hence increased transportation requirements of bioenergy, such problems are likely to be exacerbated rather than alleviated with the transition from fossil fuels to biomass-based fuels. It is important to note that this is not relevant only for direct disturbances to fuel supply (e.g. flooding of inland waterways used for barge transport of wood pellets) but also for indirect disturbances such as damages to communications infrastructure on which all modern day supply chains are highly reliant (Swedish Civil Contingencies Agency 2009).

All these problems make wood fuel supply chains vulnerable to disturbances, weather-related or other. In addition, there is also the directly weather-related issue that pellets have to be kept away from water[12]. For example, it has been reported that loading of pellets on ships destined for export from British Columbia is stopped during rains (Bradley et al. 2009; Dahlberg 2010; Hashemi 2013). Scenarios indicate that large parts of British Columbia will become wetter with climate change, which could exacerbate these problems (Lemmen et al. 2008).

In the Nordic region, solid biofuels are a key component of the energy systems of Denmark, Finland and Sweden and there is an established trade of wood chips, especially from Russia, Estonia and Latvia to Sweden and Denmark (Lamers et al., 2012). Thus, ensuring that these supply chains are

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[12] It is important to note that moisture-related logistics problems are not limited to modern bioenergy carriers, but can be a very serious concern in traditional use of fuelwood in developing countries as well (Hossain et al. 2004).

resilient to the consequences of climate change is an increasingly important factor for general energy security, but one that has so far been analyzed to a very small degree (Swedish Energy Agency 2012b). Here, there are potential benefits from climate change in the Nordic region. Ice build-up is a recurring problem for Baltic Sea shipping (Lamers et al., 2012) and one that could be alleviated by warmer winters.

Storage of biomass is another factor that could be impacted by a warmer climate. If wood chips are stored for longer periods of time, microbial activity can lead to large increases in temperatures that eventually may result in fire. A warmer and moister climate would mean better conditions for microbes to thrive which would lead to an increased risk of spontaneous combustion (Gode and Holmgren 2007).

An advantage of *bioelectricity* is that generation can take place close to large consumer regions, which is an advantage in comparison with, e.g., hydropower stations that tend to require long-distance power lines. Transmission over long distance could constitute a vulnerability as it requires very large high-voltage power lines that could be vulnerable to weather disturbances, such as windthrows (Swedish Energy Agency 2006), ice storms (Chang et al. 2007) or wildfires (Kearney 2013).

6 Mitigation-adaptation synergies and conflicts in bioenergy systems

As was discussed in chapter 5, the expected impacts of climate change on bioenergy systems are likely to come in many forms, be both positive and negative, and affect bioenergy supply chains from the cultivation of biomass to its conversion into useful energy. In this section, focus is on the possible conflicts and synergies between climate change mitigation - in the form of bioenergy systems - and climate change adaptation ambitions and implementations.

6.1 Climate change adaptation in bioenergy supply chains

Whereas research on adaptation in bioenergy systems as such is only really in its infancy, climate effects on, and adaptation in, forestry and agriculture has been studied for a relatively long time. Many findings from research on these two sectors can hence be extrapolated into bioenergy systems. Such adaptation measures could include irrigation schemes or introduction of new species or crop varieties. The latter process can occur autonomously to a certain extent (as plants continuously and naturally adapt to new external conditions) but can also be aided by human intervention (Easterling et al. 2007). Similarly, new management systems in forestry might be necessary to prevent damage from extreme weather events (Swedish Forest Agency 2006).

6.1.1 Trade as a means of adapting

It is important to note the value of bioenergy trade itself as a means of adapting to climate change. This point is made in the context of agricultural markets by Easterling et al (2007) but is equally relevant for bioenergy systems. Integration through trade of geographically separated bioenergy markets means that climate effects on supply or demand can be distributed between regions, countries or continents. In the case of crop failure in one specific region, this can be alleviated by increased imports from another region (Nelson et al. 2009). Although this could very well be at a higher cost, the effects of a region-specific supply/demand shock will be less severe than if there was no trade.

Examples of the use of trade to balance regional supply/demand fluctuations are continuously seen in markets for bioenergy based on seasonal crops (Gordon 2012). Similar developments have also taken place in the context of extreme weather events on Nordic wood fuel markets, e.g., within Sweden in the aftermath of hurricane Gudrun in 2005 (Olsson 2006) and with imports of storm-damaged wood to Sweden from France after the cyclone Klaus in 2009 (Söderenergi 2009).

6.1.2 Adaptation measures related to bioenergy logistics

If bioenergy and especially wood fuels is to be part of a viable strategy for adaptation, climate vulnerabilities of logistics (see section 5.3) need to be addressed. A solution to many of the problems associated with transport of wood pellets is to treat the biomass with a process known as *torrefaction* before pelletization and transportation to the end-user. Torrefaction is a process similar to the one used during roasting of coffee beans. The biomass is heated to about 300 °C in a low-oxygen atmosphere, driving off all moisture and parts of the volatile matter content. The result is a product with a significantly higher energy density that is also purported to be a lot less vulnerable to water contamination. This could potentially provide a means to increase climate resilience of biomass supply chains (Koppejan et al. 2012; Deutmeyer et al. 2012).

6.1.3 Perennial grasses

In terms of combining climate mitigation and adaptation in bioenergy, there is much to be said for the potential of perennial grasses to provide both renewable energy and reductions in climate vulnerability. As energy crops, perennial grasses such as *Miscanthus spp*., switchgrass (*Panicum virgatum)* and reed canary grass (*Phalaris arundinacea)* have many preferable characteristics, including high yields, high water productivity, low moisture contents, good competitiveness against weeds and low demand for fertilizer (Lewandowski et al. 2003; Berndes 2008). In terms of water use, commercialization of 2nd generation liquid biofuels based on perennial grasses would be highly beneficial. For example, production of cellulosic ethanol from switchgrass uses very marginal amounts of water relative to current production of corn ethanol (US DOE 2013). The extensive root systems of perennial grasses mean less need for irrigation and can also help prevent erosion (Glover et al. 2007; van Dam et al. 2009). Reed canary grass is on the other hand tolerant to wet areas and is commonly cultivated on peat bogs in Finland, a practice which has been shown to reduce GHG emissions from the bogs (Mander et al. 2012).

However, one potential problem with perennial grasses is that the same properties that make them suitable as raw material for bioenergy also introduces the risk that they become invasive. In fact, all of the above mentioned grasses are classified as noxious weeds or invasive species in several states in the US. Hence, it is imperative that implementation of bioenergy based on perennial grasses is conducted with utmost care and with local conditions and vulnerabilities taken into account (Glaser and Glick 2012).

6.1.4 Utilization of harvest residues

Harvest residues from agricultural crops have been suggested as potentially important source of raw material for bioenergy. However, in the perspective of climate change adaptation, it is important to note that harvest residues left on the field also are an important source of soil organic compounds needed to preserve soil vitality (Berndes et al. 2013). A similar trade-off exists for forest residues, which are widely used for energy purposes in especially Finland and Sweden. Depending on soil conditions, removal of harvest residues could mean nutrient deficiencies at the logging site, which in turn could result in impaired long-term productivity of the site.

In addition, forest residues are also used in the logging operations. Tops and branches are spread out on the forest floor to reduce damage from harvesting machinery in the form of soil compaction (Eliasson and Wästerlund 2007). This is especially important on moist un-frozen soils. In other words, there is a certain trade-off between using the forest residues to reinforce the soil or to use them for energy purposes (Eliasson 2005). In the Nordic countries, climate change is expected to bring about warmer winters and more precipitation, which could increase the need for the use of harvest residues as soil protection rather than as fuel.

6.1.5 Bioenergy supply from agroforestry systems

Agroforestry is a term that includes all "*land-use systems and technologies where woody perennials […] are deliberately used on the same land-management units as agricultural crops and/or animals*" (Nair 1993, p.13). Examples of agroforestry systems are plentiful and can be found in most parts of the world, although they are most common in tropical countries. Agroforestry systems can be characterized by their components as follows (Nair 1993):

- Agrisilvicultural systems, composing of a mixture of agricultural crops and trees
- Silvopastoral, which combines pasture and cultivation of trees
- Agrosilvopastoral, where pasture is combined with both agricultural crops and trees

A common theme and a defining trait of all agroforestry systems is their capacity to procure several different products and/or services from the same plot of land. In addition, agroforestry systems tend to function simultaneously in two (or more) time frames, e.g., with a seasonal or annual perspective in the case of the agricultural crops and a multi-year perspective for the trees. Moreover, relative to conventional agriculture, agroforestry can have many beneficial effects that are especially relevant in a context of climate change adaptation. Root systems of trees help stabilize the soil and conserve soil moisture (Verchot 2007). From a mitigation perspective, agroforestry systems can act as carbon sinks or as a source of bioenergy in the form of wood fuel from the trees (Kürsten 2000; Gruenewald et al. 2007).

Agroforestry could thus be a valuable means of combining mitigation and adaptation. As was discussed in section 4.1, a problem with combining implementation of mitigation and adaptation is that the two concepts exist in different time frames, with adaptation providing immediate benefits whereas mitigation might only have effects in a time frame of several decades or more. In agroforestry, there is a possibility of bridging this time gap by combining annual crops that provide short-term goods in the form of food crops with trees that provide both short-term adaptation benefits - improving soil resilience – and long-term mitigation benefits in the form of renewable energy or carbon sequestration (Verchot 2007).

6.2 Systemic mitigation-adaptation inter-relationships pertaining to bioenergy

6.2.1 Indirect adaptation effects

The debate on Indirect Land Use Change (ILUC) in the context of cultivation of bioenergy crops has highlighted the complexities of bioenergy markets. The interconnections of bioenergy with other markets and the global extent of bioenergy markets means that increased demand for bioenergy can have spillover effects in other markets in regions very far from the actual site of cultivation (Berndes et al. 2013). The focus of the ILUC debate has been on the consequence on bioenergy life cycle GHG emissions of including ILUC effects, but the reasoning can easily be extrapolated to adaptation effects. An example could be if increased demand for bioethanol from the Nordic countries leads to expansion of farmland into erosion-prone areas in the US for the purpose of planting corn (recall Box 2).

To an extent, the ILUC processes that lead to adverse changes in carbon stock could coincide with processes that lead to reductions in adaptive capacity, but these potential problems have not yet been investigated to any significant degree. The great complexities and uncertainties associated with ILUC analysis are not encouraging when it comes to identifying relevant measures or policy prescriptions (Ahlgren and Börjesson 2011), but this is still an issue that could be well served by increased attention from researchers as well as policy makers. Given the severe impacts of climate change on tropical regions and the low adaptive capacities of tropical countries, the uncertainty of ILUC becomes especially important in a sustainable development context. The Nordic countries have high ambitions when it comes to development aid, and thus more attention in development cooperation to the potential implications of land use change would be valuable.

6.2.2 Adaptation inter-relationships between bioenergy and hydropower

It is important to emphasize that bioenergy trade is not necessarily limited to trade in fuels, but could also entail trade in energy carriers derived from biomass, such as electricity. In this context, it is worthwhile to note the potential adaptation-mitigation synergies of an increasingly integrated European electricity network. This could help even out climate stress between on the one hand Southern Europe, where energy demand will increase and hydropower supply will decrease (Lehner et al. 2005; Hamududu and Killingtveit 2012), and on the other hand the Nordic countries, where an increase in energy supply from both bioenergy and hydro is expected to coincide with reduced demand.

The inter-relationships between hydropower and bioenergy have been analyzed in other geographical contexts as well. For example, Malawi is very dependent on hydropower and has a significant sugar cane processing industry, where electricity can be produced based on the by-product bagasse. This provides an opportunity to diversify the country's electricity production mix, thereby reducing climate change vulnerability (Johnson and Jumbe 2013). However, analysis of the situation in Brazil indicates that it is difficult to predict the value of this type of strategy. Brazil relies to a very large degree on hydropower for its electricity supply with 85% of all electricity produced in the country coming from hydro. This is positive in the sense that it provides Brazil with large amounts of renewable electricity, but it also means that the country is vulnerable to droughts. Severe drought-induced disturbances in electricity supply were seen in, e.g., 2000 and 2001 (US EIA 2012). Climate change is expected to bring about an increase in the vulnerability of electricity supply especially in the poorer regions of Brazil (de Lucena et al. 2009). One way to alleviate this problem could be an increase in the share of electricity from sugar cane processing by-products or using small scale biodiesel generators (Pires de Campos et al. 2004; Ebinger and Vergara 2011). However, this approach is potentially problematic as well. Brazil is a large country with varying climate conditions, and depending on the development of regional weather patterns, both soy bean (commonly used as raw material for biodiesel) and sugar cane production could be both positively and negatively affected by climate change (de Lucena et al. 2009; Ebinger and Vergara 2011). The actual correlations in any given region between the climate impacts on production potentials of bioenergy and hydropower will thus have important consequences.

6.2.3 Reduced demand for bioheat -> reduced supply of bioelectricity?

In Sweden, Denmark and Finland, biomass-based heat is commonly produced in combined heat and power (CHP) plants, i.e., with electricity and district heating produced in tandem in the same facilities. This means that the electricity output of CHP plants depends on the production of district heating, and in turn on the demand for heat in the local region. A reduction in heat demand could thus lead to a decrease in the production of biomass-based electricity, since CHPs need a heat sink to produce electricity (Gode et al. 2007; cf. Åberg et al. 2012).

6.2.4 Adaptation benefits from trade in waste-to-energy?

In terms of impacts from climate change on waste-to-energy, the actual climate change vulnerabilities of markets for combustible waste have been deemed rather insignificant (Bogner et al.

2007). This could mean that waste-to-energy is more resilient to climate change than, e.g., bioenergy systems based on virgin biomass where productivity and supply can be sensitive to climate-related disturbances. However, vulnerabilities in the waste sector as a whole are far from negligible, especially when it comes to uncontrolled waste disposal, which can introduce severe hazards in case of flooding. Climate change impacts on controlled landfill sites are expected to be less severe but there also seems to be a certain lack of integration of climate change adaptation into planning of landfills. For example, in the US Midwest, landfills are required only to withstand impacts from a 25-year storm (US EPA 2013) and recent studies have highlighted the potentially detrimental effects of flooding of landfills (Laner et al. 2009).

This means that waste combustion could be a viable adaptation-mitigation strategy as it can provide life-cycle GHG emission reductions and reduce climate risks related to other waste management options, i.e., if waste is combusted for energy purposes instead of being landfilled. In this context, it is however important to note that the potential vulnerabilities of waste-to-energy logistics and fuel transportation systems are similar to those for solid biomass fuels in general.

There are several issues of controversy surrounding waste combustion and trade in waste-to-energy. Other options higher up the waste hierarchy could be preferable to waste combustion if the end goal is to optimize resource efficiency. In particular, the creation of demand for waste could work against the ultimate goal of preventing the generation of waste. There is also the so-called “proximity principle” that states that treatment of hazardous wastes should take place as close to the source as possible (Krueger 1999). However, if trade in waste enables a move up the waste hierarchy, rigid adherence to the proximity principle might not be the most productive way forward.

6.3 SWOT analysis of bioenergy systems in a changing climate

In order to summarize the different aspects of bioenergy as an adaptation strategy for the Nordic countries in a changing climate, a SWOT (Strength-Weaknesses-Opportunities-Threats) matrix consisting of key issues has been composed (Table 1).

Strengths	Weaknesses
• Off-the-shelf technology => low-cost implementation • Fuel-based, can be integrated rapidly within fossil fuel systems • Integration with forestry & agriculture means that lessons can be learned from available adaptation work in these sectors	• Interaction with other sectors leads to very complex markets • Logistics sensitive to disturbances • High operating costs compared to other renewables
Opportunities	**Threats**
• Bioenergy trade provides geographical hedging and risk sharing • In the Nordic region, reduced demand, higher crop yields and more rapid forest growth implies a possibility to use trade to compensate for shortfalls elsewhere • Increased production and reduced demand opens up possibilities for Nordic exports • Trade in waste-to-energy can create incentives to move up the waste hierarchy and reduce climate-sensitive waste management practices • Expanded bioenergy markets can support sustainable and well-managed wood fuel production (e.g. based on agroforestry) • Dissemination of perennial crops can support adaptation • Bioenergy can compensate for climate-induced shortfalls in production of hydroelectricity	• Increases competition over scarce land resources, which could contribute to increased deforestation and higher food prices, already risk issues as a result of climate change • Increased demand for biofuels could lead to expansion of annual crops into currently forested areas & increase threats of erosion and associated problems • Sector complexities and lack of political consistency could lead to reduced investor confidence and public support • Residues from agriculture and forestry could be of more value as soil protection than as fuels • Co-occurring climate-induced disruptions in supply of hydropower and bioelectricity

Table 1. Problems and possibilities pertaining to bioenergy and climate change presented in a SWOT framework.

As can be seen in Table 1, there are plenty of important issues to take into account if mitigation-adaptation aspects are to be included as a component of policies on bioenergy markets and bioenergy trade. The conflicts and synergy effects can be seen in all steps of the bioenergy supply chain itself and extends beyond it as a result of the interconnections between bioenergy markets on the one hand and the energy, agriculture and forestry sectors on the other hand.

7 Concluding discussion and suggestions for further research

In this review, currently available research and analysis on mitigation-adaptation inter-relationships in the context of bioenergy systems and trade have been investigated and synthesized. Given that little attention has been paid thus far to the climate adaptation implications of bioenergy trade and biomass supply chains, a number of issues that necessitate further inquiry have been identified.

In a global perspective, bioenergy and hydropower are the two most important sources of renewable energy. Both could also be very sensitive to climate change. The extent to which climate change impacts on hydro power compensates for shortfalls in bioenergy production and vice versa in different regions is a field of study that demands more attention. In the Nordic region, the general view is that the productive potential of both hydropower and bioenergy is expected to increase with climate change, but whether this is valid for all scenarios is not clear. Furthermore, this line of thinking should be expanded to include other renewables as well, in particular wind and solar which are expanding rapidly and are expected to constitute key components in mitigation strategies, especially in the longer term. In the Nordic perspective, climate change effects on the interaction between wind energy (prevalent especially in Denmark and Sweden), hydropower (Norway and Sweden) and bioenergy (Denmark, Finland and Sweden) should be analyzed. In addition, the potential gains from linking Iceland to the European electricity market should be expanded to include a perspective of climate change adaptation.

Specifically for bioenergy used in heat & power production, it is worth noting the lack of comprehensive analysis of the vulnerability of the supply of solid biofuels to district heating and/or combined heat & power plants in the Nordic region. The dependence on continuous fuel supply means that external disturbances in the form of extreme weather events could have detrimental effects on urban societies. This is especially relevant for Denmark, Finland and Sweden where bioenergy-based district heating is the most common form of space heating in urban dwellings.

An additional issue that should be addressed is the need in Nordic adaptation policy for increased awareness of mitigation-adaptation inter-relationships in general and aspects pertaining to bioenergy systems in particular. Several of the Nordic countries do briefly touch upon how climate change could affect bioenergy production potential, but this review has showed that the topic requires increased attention from policy makers. One field that could be explored further is the ways in which the growing productivity in Nordic agriculture and forestry can be used to support long-term reductions in climate risk on an international level.

Although this review does not address waste management per se, waste combustion is linked to bioenergy systems and thus waste management is indirectly connected to bioenergy markets and bioenergy trade. Climate change impacts on management systems for municipal solid waste is an area of research that has not been investigated to a sufficient degree. The same is true for investigating the possibilities of adaptation-mitigation synergies in waste-to-energy, but should also include other options higher up the waste hierarchy.

Finally, the impact of indirect land use change on adaptive capacities in third party regions is a matter that closely relates to and is an extension of the ongoing discussions about the impact of indirect land use change on life cycle carbon emissions from bioenergy systems. On the one hand it could be argued that indirect adaptation effects is a topic that requires increased attention. On the other hand, bioenergy's potential for climate change mitigation cannot be realized if more and more criteria are added onto what is an already extensive list of indirect issues to consider, especially considering the total lack of sustainability criteria for the fossil fuels with which it competes. Although the complexities of bioenergy markets require comprehensive and cohesive regulation to steer implementation in the correct direction, this is likely to be a process characterized by diminishing marginal returns. Consistent and cohesive long-term policies are a necessity for bioenergy to fulfill its potential as a tool for mitigation as well as adaptation.

8 References

Aaheim (ed.), A. (2009) *Konsekvenser Av Klimaendringer, Tilpasning Og Sårbarhet I Norge ("Consequences of Climate Change, Adaptation and Vulnerability in Norway)*. CICERO Report 2009:04. Center for International Climate and Environmental Research - Oslo (CICERO). http://www.cicero.uio.no/media/7442.pdf.

Åberg, M., Widén, J. and Henning, D. (2012) 'Sensitivity of district heating system operation to heat demand reductions and electricity price variations: A Swedish example'. *Energy*, 41(1). 525–40. doi:10.1016/j.energy.2012.02.034.

ACEA (2013) *New Passenger Car Registrations - Breakdown by Specification*. European Automobile Manufacturer's Organisation. http://www.acea.be/images/uploads/files/2013Q1PC_Reg_by_Segment_Characteristics_diesel.pdf.

Adger, W. N., Agrawala, S., Mirza, M. M. Q., Conde, C., O'Brien, K., et al. (2007) 'Assessment of Adaptation Practices, Options, Constraints and Capacity'. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007*, M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson (eds.). Cambridge University Press, Cambridge, UK. 717–43.

AEBIOM (2013) *European Bioenergy Outlook 2013*. European Biomass Association.

AEBIOM (2012) *European Bioenergy Outlook 2012*. Brussels. http://www.aebiom.org/wp-content/uploads/file/AEBIOM%20Statistical%20Report/AEBIOM_European%20Bioenergy%20Outlook%202012sv.pdf.

Ahlgren, S. and Börjesson, P. (2011) *Indirekt Förändrad Markanvändning Och Biodrivmedel - En Kunskapsöversikt*. 73. Department of Technology & Society, Lund University. http://www.miljo.lth.se/svenska/publikationer/visaInfo.asp?ID=377.

Alakangas, E., Heikkinen, A., Lensu, T. and Vesterinen, P. (2007) *Biomass Fuel Trade in Europe*. VTT-R-03508-07. VTT/EUBIONET II.

Atanasiu, B. (2010) *The Role of Bioenergy in the National Renewable Energy Action Plans: A First Identification of Issues and Uncertainties*. IEE 08 653 SI2. 529 241. Institute for European Environmental Policy. http://www.ieep.eu/assets/753/bioenergy_in_NREAPs.pdf.

Avfall Sverige (2013) *Kapacitetsutredning 2013 – Avfallsförbränning till År 2020 ('Capacity Review 2013 - Waste Combustion until 2020')*. Avfall Sverige (Swedish Waste Management and Recycling Association). http://www.avfallsverige.se/fileadmin/uploads/Rapporter/Förbränning/E2013-04.pdf.

Bailis, R., Rujanavech, C., Dwivedi, P., de Oliveira Vilela, A., Chang, H. and de Miranda, R. C. (2013) 'Innovation in charcoal production: A comparative life-cycle assessment of two kiln technologies in Brazil'. *Energy for Sustainable Development*, 17(2). 189–200. doi:10.1016/j.esd.2012.10.008.

Benzie, M., Wallgren, O. and Davis, M. (2013) *Adaptation without Borders? How Understanding Indirect Impacts Could Change Countries' Approach to Climate Risks*. Stockholm Environment

Institute. http://www.sei-international.org/mediamanager/documents/Publications/Climate/SEI-DB-2013-Adaptation-Without-Borders.pdf.

Bergström, S., Andreasson, J., Veijalainen, N., Vehviläinen, B., Einarsson, B., et al. (2012) 'Modelling Climate Change Impacts on the Hydropower System'. *Climate Change and Energy Systems: Impacts, Risks and Adaptation in the Nordic and Baltic Countries* Nordic Council of Ministers, Copenhagen, Denmark.

Berndes, G. (2008) *Water Demand for Global Bioenergy Production: Trends, Risks and Opportunities*. ISBN 978-3-9396191-21-9. Wissenschaftlicher Beirat der Bundesregierung globale umWeltveränderungen, Gothenburg, Sweden & Berlin, Germany. http://www.wbgu.de/fileadmin/templates/dateien/veroeffentlichungen/hauptgutachten/jg2008/wbgu_jg2008_ex02.pdf.

Berndes, G., Ahlgren, S., Börjesson, P. and Cowie, A. L. (2013) 'Bioenergy and land use change—state of the art'. *Wiley Interdisciplinary Reviews: Energy and Environment*, 2(3). 282–303. doi:10.1002/wene.41.

Beurskens, L. W. M., Hekkenberg, M. and Vethman, P. (2011) *Renewable Energy Projections as Published in the National Renewable Energy Action Plans of the European Member States*. ECN-E--10-069. ECN. http://www.ecn.nl/docs/library/report/2010/e10069.pdf.

Biowood Norway (2013) 'Biowood Norway website'. http://www.biowood.no/index_eng.asp.

Björheden, R. (2007) 'Possible effects of the hurricane Gudrun on the regional Swedish forest energy supply'. *Biomass and Bioenergy*, 31(9). 617–22. doi:10.1016/j.biombioe.2007.06.025.

Björheden, R. (2006) 'Drivers behind the development of forest energy in Sweden'. *Biomass and Bioenergy*, 30(4). 289–95. doi:10.1016/j.biombioe.2005.07.005.

Bogner, J., Abdelrafie Ahmed, M., Diaz, C., Faaij, A., Gao, Q., et al. (2007) 'Waste management'. *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)]* IPCC and Cambridge University Press.

Bowyer, C. (2010) *Anticipated Indirect Land Use Change Associated with Expanded Use of Biofuels and Bioliquids in the EU – An Analysis of the National Renewable Energy Action Plans*. Institute for European Environmental Policy. http://www.ieep.eu/news/2010/11/the-indirect-land-use-change-impact-of-biofuels-ieep-launches-analysis-of-eu-nations-projected.

Bradley, D., Diesenreiter, F., Wild, M. and Trømborg, E. (2009) *World Biofuel Maritime Shipping Study*. IEA Bioenergy Task 40 Sustainable International Bioenergy Trade. http://www.bioenergytrade.org/downloads/worldbiofuelmaritimeshippingstudyjuly120092df.pdf.

Brännlund, R., Lundmark, R. and Söderholm, P. (2010) *Kampen om skogen: koka, såga, bränna eller bevara?* SNS förlag.

Brodwin, E. (2013) 'Farmed Out: Overpumping Threatens to Deplete U.S. High Plains Groundwater: Scientific American'. *Scientific American*, 27 August. http://www.scientificamerican.com/article.cfm?id=farmed-out-overpumping-threatens-deplete-high-plains-groundwater&utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+sciam%2Fenergy-and-sustainability+%28Topic%3A+Energy+%26+Sustainability%29.

Bryngelsson, D. K., Á?hlén, A., Azar, C. and Persson, U. M. (2012) 'The effect of food–price movements on African households'. *International Journal of Agricultural Resources, Governance and Ecology*, 9(3). 121–46. doi:10.1504/IJARGE.2012.050326.

CEWEP (2012) *A Decade of Waste-to-Energy in Europe(2001-2010/11)*. Confederation of European Waste-To-Energy Plants. http://www.cewep.eu/information/publicationsandstudies/statements/ceweppublications/m_1174.

Chang, S. E., McDaniels, T. L., Mikawoz, J. and Peterson, K. (2007) 'Infrastructure failure interdependencies in extreme events: power outage consequences in the 1998 Ice Storm'. *Natural Hazards*, 41(2). 337–58. doi:10.1007/s11069-006-9039-4.

Chum, H., Faaij, A., Moreira, J., Berndes, G., Dhamija, P., et al. (2011) 'Bioenergy'. *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation* Cambridge University Press, Cambridge, UK and New York, NY, USA. 209–332.

Clarke, N., Søgaard, G. and Holt Hanssen, K. (2011) *Country Policy Assessment Report in Bioenergy: Norway*. Ås, Norway. http://www.skogoglandskap.no/filearchive/bp_task_3_3_bsr_country_reports_norway.pdf.

Council of the European Union (2009) 'DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC'. *Official Journal of the European Union*, . http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32009L0028:en:NOT.

Dahlberg, A. (2010) *Consequences of New Sources of Supply on Wood Fuel Prices*.

Danish Energy Agency (2013) *Annual Energy Statistics 2012*. http://www.ens.dk/info/tal-kort/statistik-nogletal/arlig-energistatistik.

Danish EPA (2013) *Affaldsstatistik 2011 ('Waste Statistics 2011')*. Danish Environmental Protection Agency. http://www.mst.dk/NR/rdonlyres/E75D350F-8E07-47D5-83A3-3496A07AA716/157424/Affaldsstatistik2010.pdf.

Dansk Skovforening, Skovdyrkerforeningerne and HedeDanmark a/s (2013) *Danmarks Forsyning Af Træflis I Fremtidens Energimarked ('Danish Supply of Wood Chips in the Future Energy Market')*. Dansk Skovforening, Skovdyrkerforeningerne og HedeDanmark a/s. http://www.skovforeningen.dk/media/traeflis-fremtid-energimark.pdf.

De Lucena, A. F. P., Szklo, A. S., Schaeffer, R., de Souza, R. R., Borba, B. S. M. C., et al. (2009) 'The vulnerability of renewable energy to climate change in Brazil'. *Energy Policy*, 37(3). 879–89. doi:10.1016/j.enpol.2008.10.029.

Deutmeyer, M., Bradley, D., Hektor, B., Hess, R., Tumuluru, J., Nikolaisen, L. and Wild, M. (2012) *Possible Effect of Torrefaction on Biomass Trade*. IEA Bioenergy Task 40 Sustainable International Bioenergy Trade. http://www.bioenergytrade.org/downloads/t40-torrefaction-2012.pdf.

Diesel Technology Forum (2013) *U.S. Diesel Car Registrations Increase By 24%*. http://www.dieselforum.org/news/u-s-diesel-car-registrations-increase-by-24-hybrids-up-33-total-car-market-registrations-increase-just-2-7-since-2010.

Directorate for Civil Protection and Emergency Planning (2008) *Klimatilpasning I Norge: Regjeringens Arbeid Med Tilpasning Til Klimaendringene*. (Adapting to climate change in Norway: The Government's efforts to adapt to climate change.). Oslo. http://www.regjeringen.no/upload/MD/Vedlegg/Klima/Klimatilpasning/Klimatilpasning_redegjorelse150508.pdf.

Dow, K., Berkhout, F., Preston, B. L., Klein, R. J. T., Midgley, G. and Shaw, M. R. (2013) 'Limits to adaptation'. *Nature Climate Change*, 3(4). 305–7. doi:10.1038/nclimate1847.

Easterling, W. E., Aggrawal, P. K., Batima, P., Brander, K., Erda, L., et al. (2007) 'Food, fibre and forest products'. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, C. E. Hanson and C. E. Hanson (eds.). Cambridge University Press, Cambridge. 273–313.

Ebinger, J. and Vergara, W. (2011) *Climate Impacts on Energy Systems : Key Issues for Energy Sector Adaptation*. The World Bank. http://ideas.repec.org/b/wbk/wbpubs/2271.html.

Edenhofer, O., Knopf, B., Barker, T., Baumstark, L., Bellevrat, E., et al. (2010) 'The Economics of Low Stabilization: Model Comparison of Mitigation Strategies and Costs'. *The Energy Journal*, 31(01). doi:10.5547/ISSN0195-6574-EJ-Vol31-NoSI-2.

Eklöf, J. K., Ekerholm, H. and Mårald, E. (2012) 'Promoting Ethanol in the Shadow of Oil Dependence: 100 years of arguments and frictions in Swedish politics'. *Scandinavian Journal of History*, 37(5). 621–45. doi:10.1080/03468755.2012.725677.

Eliasson, L. (2005) 'Effects of forwarder tyre pressure on rut formation and soil compaction'. *Silva Fennica*, 39(4).

Eliasson, L. and Wästerlund, I. (2007) 'Effects of slash reinforcement of strip roads on rutting and soil compaction on a moist fine-grained soil'. *Forest Ecology and Management*, 252(1–3). 118–23. doi:10.1016/j.foreco.2007.06.037.

ESPON (2011) *Climate Change and Territorial Effects on Regions and Local Economies*. European Observation Network for Territorial Development and Cohesion (ESPON). http://www.espon.eu/export/sites/default/Documents/Projects/AppliedResearch/CLIMATE/ESPON_Climate_Final_Report-Part_B-MainReport.pdf.

Euractiv.com (2013) ‘MEPs deal a blow to crop-based biofuels’. *EurActiv.com*. http://www.euractiv.com/energy/meps-deal-blow-crop-based-biofue-news-529274.

EurObserver (2012) *Renewable Municipal Waste Barometer 2011*. http://www.eurobserv-er.org/pdf/baro212msw.pdf.

European Parliament and Council of the European Union (2008) ‘Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Text with EEA relevance)’. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32008L0098:EN:NOT.

Eurostat (2013a) *International Trade Statistics*. http://epp.eurostat.ec.europa.eu/portal/page/portal/international_trade/data/database.

Eurostat (2013b) *Supply, Transformation, Consumption - Renewables and Wastes (total, Solar Heat, Biomass, Geothermal, Wastes) - Annual Data*. http://epp.eurostat.ec.europa.eu/portal/page/portal/energy/data/database.

Eurostat (2013c) *Treatment of Waste Statistics*. http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Waste_statistics.

Fenger, J. ed. (2007) *Impacts of Climate Change on Renewable Energy Sources: Their Role in the Nordic Energy System*. Nordic Council of Ministers, Copenhagen.

Finnish Energy Industries (2013) *District Heating in Finland 2012*. ISSN 0786-4809. http://energia.fi/sites/default/files/district_heating_in_finland_2012_web.pdf.

Franco, J., Levidow, L., Fig, D., Goldfarb, L., Hönicke, M. and Luisa Mendonça, M. (2010) ‘Assumptions in the European Union biofuels policy: frictions with experiences in Germany, Brazil and Mozambique’. *Journal of Peasant Studies*, 37(4). 661–98. doi:10.1080/03066150.2010.512454.

Gibson, L. (2011) ‘Rubber tree chips to fuel Danish power plant | Biomassmagazine.com’. 26 October. http://biomassmagazine.com/articles/5890/rubber-tree-chips-to-fuel-danish-power-plant.

Glaas, E. (2013) *Reconstructing Noah’s Ark : Integration of Climate Change Adaptation into Swedish Public Policy*. dissertation. Linköping. http://liu.diva-portal.org/smash/record.jsf?pid=diva2:612300.

Glaser, A. and Glick, P. (2012) *Growing Risk: Addressing the Invasive Potential of Bioenergy Feedstocks*. National Wildlife Federation. http://www.nwf.org/~/media/PDFs/Wildlife/Growing%20Risk-2-FINAL-LOW-RES.ashx.

Glover, J. D., Cox, C. M. and Reganold (2007) ‘Future Farming: A Return to Roots?:’ *Scientific American*, 15 July. http://www.scientificamerican.com/article.cfm?id=future-farming-a-return-to-roots.

Gode, J., Axelsson, J., Eriksson, S., Holmgren, K., Hovsenius, G., et al. (2007) *Tänkbara Konsekvenser För Energi- Sektorn Av Klimatförändringar (‘Possible Consequences of Climate Change on the Energy Sector’)*. 07:39. Elforsk.

Gode, J. and Holmgren, K. (2007) *Konsekvenser För Bränsleförsörjningen Av Klimatförändringar: Biobränslen Och Naturgas ('Effects on Fuel Supply from Climate Change: Bioenergy and Natural Gas')*. B1869. IVL/Elforsk. http://www.ivl.se/download/18.7df4c4e812d2da6a416800072059/B1869.pdf.

Gomiero, T., Paoletti, M. G. and Pimentel, D. (2010) 'Biofuels: Efficiency, Ethics, and Limits to Human Appropriation of Ecosystem Services'. *Journal of Agricultural and Environmental Ethics*, 23(5). 403–34. doi:10.1007/s10806-009-9218-x.

Gordon, M. (2012) 'US loses ethanol exporter status after Midwestern drought'. *Platts' The Barrel*, 13 November. http://blogs.platts.com/2012/11/13/ethanol_exporter/.

Gruenewald, H., Brandt, B. K. V., Schneider, B. U., Bens, O., Kendzia, G. and Hüttl, R. F. (2007) 'Agroforestry systems for the production of woody biomass for energy transformation purposes'. *Ecological Engineering*, 29(4). 319–28. doi:10.1016/j.ecoleng.2006.09.012.

Hakkila, P. (2006) 'Factors driving the development of forest energy in Finland'. *Biomass and Bioenergy*, 30(4). 281–88. doi:10.1016/j.biombioe.2005.07.003.

Hamududu, B. and Killingtveit, A. (2012) 'Assessing Climate Change Impacts on Global Hydropower'. *Energies*, 5(12). 305–22. doi:10.3390/en5020305.

Hashemi, S. Z. (2013) 'Studies on encapsulation of pelletized biomass'. https://circle.ubc.ca/handle/2429/44683.

HEC/CABI (2010) *Biofuels and Land Use Change: A Science and Policy Review*. Hart Energy Consulting/CABI. http://www.globalbioenergy.org/uploads/media/1010_HART_CABI_-_Land_Use_Change_Science_and_policy_review_SC.pdf.

Heinimö, J. and Alakangas, E. (2011) *Market of Biomass Fuels in Finland – an Overview 2009*. Research Report 19. Lappeenranta University of Technology, Institute of Energy Technology. http://www.bioenergytrade.org/downloads/iea-task-40-country-report-2011-finland.pdf.

Hossain, I., Tamim, M. and Gomes, E. (2004) 'Country study: Bangladesh'. *Seeing the light: adapting to climate change with decentralized renewable energy in developing countries*, H. D. Venema and M. Cisse (eds.). International Institute for Sustainable Development/Institut International du Developpement Durable.

Iceland's Ministry of Industries and Innovation (2012) *The Icelandic National Renewable Energy Action Plan for the Promotion of the Use of Energy from Renewable Sources in Accordance with Directive 2009/28/EC and the Commission Decision of 30 June 2009 on a Template for the National Renewable Energy Action Plans.* www.atvinnuvegaraduneyti.is/media/Skyrslur/NREAP.pdf.

IPCC (2012) *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. A Special Report of the Intergovernmental Panel on Climate Change Working Groups I and II (Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley, eds.). Cambridge University Press, Cambridge, UK, and New York. http://ipcc-wg2.gov/SREX/.

IPCC (2007) *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007*. M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson (eds.). Cambridge University Press, Cambridge, UK, and New York.

Iwai, Y. ed. (2002) *Forestry and the Forest Industry in Japan*. UBC Press, Vancouver, BC.

Johansson, A. (2012) 'Export of wood pellets from British Columbia'. 14 September. http://stud.epsilon.slu.se/4807/.

Johnson, F. X. (2011) 'Regional-Global Linkages in the Energy-Climate-Development Policy Nexus: The Case of Biofuels in the EU Renewable Energy Directive'. *Renewable Energy Law and Policy Review*, 2011. 91.

Johnson, F. X. and Jumbe, C. (2013) *Energy Access and Biomass Resource Transitions in Malawi*. SEI Policy Brief. Stockholm Environment Institute, Stockholm. http://www.sei-international.org/publications?pid=2238.

Johnson, F. X., Pacini, H. and Smeets, E. (2012) *Transformations in EU Biofuels Markets under the Renewable Energy Directive and the Implications for Land Use, Trade and Forests*. CIFOR Occasional Paper 78. Center for International Forestry Research, Bogor, Indonesia. http://www.cifor.org/online-library/browse/view-publication/publication/3775.html.

Juhola, S., Klein, R. J. T., Bohman, A., Davíðsdóttir, B., Eskeland, G., et al. (2012) *NORD-STAR Science Implementation Plan 2011–2015*. Nordic Centre of Excellence for Strategic Adaptation Research, Norden Top-level Research Initiative, Oslo, Norway.

Junginger, M., Goh, C. S. and Faaij, A. (2013) *International Bioenergy Trade: History, Status & Outlook on Securing Sustainable Bioenergy Supply, Demand and Markets (Lecture Notes in Energy)*. 2014 edition. Springer.

Junginger, M., van Dam, J., Zarrilli, S., Ali Mohamed, F., Marchal, D. and Faaij, A. (2011) 'Opportunities and barriers for international bioenergy trade'. *Energy Policy*, 39(4). 2028–42. doi:10.1016/j.enpol.2011.01.040.

Juroszek, P. and von Tiedemann, A. (2013) 'Plant pathogens, insect pests and weeds in a changing global climate: a review of approaches, challenges, research gaps, key studies and concepts'. *The Journal of Agricultural Science*, 151(02). 163–88. doi:10.1017/S0021859612000500.

Kalt, G. and Kranzl, L. (2012) 'An assessment of international trade related to bioenergy use in Austria—Methodological aspects, recent developments and the relevance of indirect trade'. *Energy Policy*, 46. 537–49. doi:10.1016/j.enpol.2012.04.026.

Kearney, L. (2013) 'Yosemite blaze: California's fast-moving wildfire threatens San Francisco power lines'. *The Independent*, 24 August. http://www.independent.co.uk/news/world/americas/yosemite-blaze-californias-fastmoving-wildfire-threatens-san-francisco-power-lines-8783210.html.

Kellomäki, S., Alam, A. and Kilpeläinen, A. (2012) 'Forest biomass for fuel production – potentials, management and risks under warmer climate'. *Climate Change and Energy Systems: Impacts, Risks and Adaptation in the Nordic and Baltic Countries* Nordic Council of Ministers, Copenhagen, Denmark.

Klein, R. J. T., Huq, S., Denton, F., Downing, T. E., Richels, R. G., Robinson, J. B. and Toth, F. L. (2007) 'Inter-relationships between adaptation and mitigation'. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* Cambridge University Press, Cambridge, UK. 745–77.

Klein, R. J. T. and Juhola, S. (2013) *A Framework for Nordic Actor-Oriented Climate Adaptation Research*. NORD-STAR Working Paper, 2013-1. Nordic Center of Excellence for Strategic Adaptation Research. www.nord-star.info/workingpapers.

Klein, R. J. T., Schipper, E. L. F. and Dessai, S. (2005) 'Integrating mitigation and adaptation into climate and development policy: three research questions'. *Environmental Science & Policy*, 8(6). 579–88. doi:10.1016/j.envsci.2005.06.010.

Koppejan, J., Sokhansanj, S., Melin, S. and Madrali, S. (2012) *Status Overview of Torrefaction Technologies*. Enschede, The Netherlands. http://www.ieabcc.nl/publications/IEA_Bioenergy_T32_Torrefaction_review.pdf.

Kovacs, A. (2013) *Green Gas Grids Project Working Group on Biomethane Trade Discussion Paper #2*. Green Gas Grids/Intelligent Energy Europe. http://www.greengasgrids.eu/fileadmin/greengas/media/Downloads/Documentation_from_the_GreenGasGrids_project/GGG_discussion_paper_Trade_2013.pdf.

Krueger, J. (1999) *International Trade and the Basel Convention*. Earthscan.

Kürsten, E. (2000) 'Fuelwood production in agroforestry systems for sustainable land use and CO2-mitigation'. *Ecological Engineering*, 16, Supplement 1. 69–72. doi:10.1016/S0925-8574(00)00054-9.

Kurz, W. A., Dymond, C. C., Stinson, G., Rampley, G. J., Neilson, E. T., et al. (2008) 'Mountain pine beetle and forest carbon feedback to climate change'. *Nature*, 452(7190). 987–90. doi:10.1038/nature06777.

Lamers, P. (2012) *International Biodiesel Markets: Developments in Production and Trade*. UFOP-Schriften. ECOFYS, Berlin, Germany. http://www.ecofys.com/files/files/ecofys_ufop_2012_internationalbiodieselmarkets.pdf.

Lamers, P., Hamelinck, C., Junginger, M. and Faaij, A. (2011) 'International bioenergy trade—A review of past developments in the liquid biofuel market'. *Renewable and Sustainable Energy Reviews*, 15(6). 2655–76. doi:10.1016/j.rser.2011.01.022.

Lamers, P., Junginger, M., Dymond, C. C. and Faaij, A. (2013) 'Damaged forests provide an opportunity to mitigate climate change'. *GCB Bioenergy*, . n/a–n/a. doi:10.1111/gcbb.12055.

Lamers, P., Junginger, M., Hamelinck, C. and Faaij, A. (2012) 'Developments in international solid biofuel trade—An analysis of volumes, policies, and market factors'. *Renewable and Sustainable Energy Reviews*, 16(5). 3176–99. doi:10.1016/j.rser.2012.02.027.

Lamers, P., Junginger, M., Marchal, D., Schouwenberg, P.-P. and Cocchi, M. (2012) *Global Wood Chip Trade for Energy*. IEA Bioenergy Task 40 Sustainable International Bioenergy Trade. http://www.bioenergytrade.org/downloads/t40-global-wood-chips-study_final.pdf.

Laner, D., Fellner, J. and Brunner, P. H. (2009) 'Flooding of municipal solid waste landfills — An environmental hazard?' *Science of The Total Environment*, 407(12). 3674–80. doi:10.1016/j.scitotenv.2009.03.006.

Lehner, B., Czisch, G. and Vassolo, S. (2005) 'The impact of global change on the hydropower potential of Europe: a model-based analysis'. *Energy Policy*, 33(7). 839–55.

Lemmen, D. S., Warren, F. J., Lacroix, J. and Bush, E. (2008) *From Impacts to Adaptation: Canada in a Changing Climate 2007*. http://geogratis.gc.ca/api/en/nrcan-rncan/ess-sst/93b415e7-ffb7-52ed-a5b1-3c4b1555ab88.html.

Lewandowski, I., Scurlock, J. M. O., Lindvall, E. and Christou, M. (2003) 'The development and current status of perennial rhizomatous grasses as energy crops in the US and Europe'. *Biomass and Bioenergy*, 25(4). 335–61. doi:10.1016/S0961-9534(03)00030-8.

Lotze-Campen, H., von Lampe, M., Kyle, P., Fujimori, S., Havlik, P., et al. (2014) 'Impacts of increased bioenergy demand on global food markets: an AgMIP economic model intercomparison'. *Agricultural Economics*, 45(1). 103–16. doi:10.1111/agec.12092.

Lund, H. (2010) 'The implementation of renewable energy systems. Lessons learned from the Danish case'. *Energy*, 35(10). 4003–9. doi:10.1016/j.energy.2010.01.036.

Mander, Ü., Järveoja, J., Maddison, M., Soosaar, K., Aavola, R., Ostonen, I. and Salm, J.-O. (2012) 'Reed canary grass cultivation mitigates greenhouse gas emissions from abandoned peat extraction areas'. *GCB Bioenergy*, 4(4). 462–74. doi:10.1111/j.1757-1707.2011.01138.x.

Maracchi, G., Sirotenko, O. and Bindi, M. (2005) 'Impacts of Present and Future Climate Variability on Agriculture and Forestry in the Temperate Regions: Europe'. *Increasing Climate Variability and Change*, J. Salinger, M. V. K. Sivakumar, and R. P. Motha (eds.). Springer Netherlands. 117–35.

Marttila, V., Granholm, H., Laanikari, J., Yrjölä, T., Aalto, A., et al. eds. (2005) *Finland's National Strategy for Adaptation to Climate Change*. Ministry of Agriculture and Forestry of Finland, Helsinki.

Meyer, S., Schmidhuber, J. and Barreiro-Hurlé Jesús (2013) *Global Biofuel Trade: How Uncoordinated Biofuel Policy Fuels Resource Use and GHG Emissions*. 48. International Centre for Trade and Sustainable Development. http://ictsd.org/downloads/2013/05/global-biofuel-trade-how-uncoordinated-biofuel-policy-fuels-resource-use-and-ghg-emissions.pdf.

Ministry for the Environment (2007) *Iceland's Climate Change Strategy*. Reykjavik. http://eng.umhverfisraduneyti.is/publications/nr/1053.

Ministry of Agriculture and Forestry (2009) *Evaluation of the Implementation of Finland's National Strategy for Adaptation to Climate Change 2009*. 4a/2009. Helsinki. http://www.mmm.fi/en/index/frontpage/climate_change_energy/adaption/evaluation_of_strategy.html.

Montgomery, D. R. (2007) *Dirt: The Erosion of Civilizations*. University of California Press, Berkeley.

Moser, S. C. (2012) 'Adaptation, mitigation, and their disharmonious discontents: an essay'. *Climatic Change*, 111(2). 165–75. doi:10.1007/s10584-012-0398-4.

Mwampamba, T. H., Ghilardi, A., Sander, K. and Chaix, K. J. (2013) 'Dispelling common misconceptions to improve attitudes and policy outlook on charcoal in developing countries'. *Energy for Sustainable Development*, 17(2). 75–85. doi:10.1016/j.esd.2013.01.001.

Nair, P. K. R. (1993) *An Introduction to Agroforestry*. Kluwer Academic Publishers in cooperation with International Centre for Research in Agroforestry, Dordrecht; Boston.

Nelson, G., Palazzo, A., Ringler, C., Sulser, T. and Batka, M. (2009) *The Role of International Trade in Climate Change Adaptation*. International Centre for Trade and Sustainable Development. http://ictsd.org/i/publications/66988/.

Neste Oil (2013) 'Flexible mix of raw materials'. *Neste Oil Website*, . http://www.nesteoil.com/default.asp?path=1,41,11991,12243,15658.

Neuman, W. (2011) 'High Corn and Soy Prices Increase Erosion Risk in Iowa'. *The New York Times*, 12 April. Business Day. http://www.nytimes.com/2011/04/13/business/13erosion.html.

Nikolaisen, L. (2012) *IEA Bioenergy Task 40 Country Report 2011 for Denmark*. IEA Bioenergy Task 40/Danish Technological Institute. http://www.bioenergytrade.org/downloads/iea-task-40-country-report-2011-denmark.pdf.

Niquidet, K., Stennes, B. and van Kooten, G. C. (2012) 'Bioenergy from Mountain Pine Beetle Timber and Forest Residuals: A Cost Analysis'. *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie*, 60(2). 195–210. doi:10.1111/j.1744-7976.2012.01246.x.

Norway Ministry of Petroleum and Energy (2012) *National Renewable Energy Action Plan under Directive 2009/28/EC: Norway*. Ref. Ares(2013)117932 - 30/01/2013. http://ec.europa.eu/energy/renewables/transparency_platform/doc/dir_2009_0028_action_plan_norway__nreap.pdf.

Norwegian Climate and Pollution Agency/Environment.no (2011) *Import and Export of Waste*. http://www.environment.no/Topics/Waste/Import-and-export-of-waste/.

Norwegian Water Resources and Energy Directorate (2006) *Hydrological Climate Change Maps of the Nordic Countries Based on RegClim HIRHAM and Rossby Centre RCAO Regional Climate Model Results*. Norwegian Water Resources and Energy Directorate, Oslo.

Oliver, R. J., Finch, J. W. and Taylor, G. (2009) 'Second generation bioenergy crops and climate change: a review of the effects of elevated atmospheric CO2 and drought on water use and the implications for yield'. *GCB Bioenergy*, 1(2). 97–114. doi:10.1111/j.1757-1707.2009.01011.x.

Olsson, O. (2006) *The Swedish Biofuel Market: Studies of Swedish Foreign Biofuel Trade and of the Consequences of Hurricane Gudrun*. Master's Thesis. Uppsala University, Uppsala. http://www.utn.uu.se/sts/cms/filarea/0605_Olsson.pdf.

Olsson, O. and Hillring, B. (2013) 'Price relationships and market integration in the Swedish wood fuel market'. *Biomass and Bioenergy*, 57. 78–85. doi:10.1016/j.biombioe.2013.01.026.

Olsson, O. and Hillring, B. (2012) '5.06 - A Global Bioenergy Market'. *Comprehensive Renewable Energy*, Ali Sayigh (ed.). Elsevier, Oxford. 75–85.

Olsson, O., Hillring, B. and Vinterbäck, J. (2012) 'Estonian-Swedish wood fuel trade and market integration: a co-integration approach'. *International Journal of Energy Sector Management*, 6(1). 75–90. doi:10.1108/17506221211216553.

Persson, U. M. (2014) 'The impact of biofuel demand on agricultural commodity prices: a systematic review'. *Submitted to Wiley Interdisciplinary Reviews: Energy & Environment*, .

Pilli-Sihvola, K., Aatola, P., Ollikainen, M. and Tuomenvirta, H. (2010) 'Climate change and electricity consumption—Witnessing increasing or decreasing use and costs?' *Energy Policy*, 38(5). 2409–19. doi:10.1016/j.enpol.2009.12.033.

Pires de Campos, C., Muylaert, M. S., Oliveira Costa, A. and Martins Henriques, R. (2004) 'Country study: Brazil'. *Seeing the light: adapting to climate change with decentralized renewable energy in developing countries*, M. Cisse and H. D. Venema (eds.). International Institute for Sustainable Development/Institut International du Developpement Durable.

Quaderer, H. and Rübig, P. (2012) *Report on the Future of the EU Energy Policy and Its Implications for the EEA*. European Economic Area (EEA) Joint Parliamentary Committee. http://www.efta.int/~/media/Documents/advisory-bodies/parliamentary-committee/jpc-reports/EEA_JPC_Report_Energy_Policy.pdf.

Roggenkamp, M. M., Barrera-Hernández, L., Zillman, D. N. and Guayo, I. del (2012) *Energy Networks and the Law: Innovative Solutions in Changing Markets*. Oxford University Press.

Rosillo-Calle, F. and Johnson, F. X. eds. (2010) *Food versus Fuel: An Informed Introduction to Biofuels*. Zed Books.

Sanders, D. J., Balagtas, J. V. and Gruere, G. P. (2012) *Revisiting the Palm Oil Boom in Southeast Asia: The Role of Fuel versus Food Demand Drivers*. 1167. International Food Policy Research Institute (IFPRI). http://ideas.repec.org/p/fpr/ifprid/1167.html.

Schipper, E. L. F. (2006) 'Conceptual History of Adaptation in the UNFCCC Process'. *Review of European Community & International Environmental Law*, 15(1). 82–92. doi:10.1111/j.1467-9388.2006.00501.x.

Schlag, N. and Zuzarte, F. (2008) *Market Barriers to Clean Cooking Fuels in Sub-Saharan Africa: A Review of Literature*. SEI Working Paper 8, 2008. Stockholm Environment Institute, Stockholm. http://www.sei-international.org/mediamanager/documents/Publications/Climate/market_barriers_clean_cooking_fuels_21april.pdf.

Schure, J., Ingram, V., Sakho-Jimbira, M. S., Levang, P. and Wiersum, K. F. (2013) 'Formalisation of charcoal value chains and livelihood outcomes in Central- and West Africa'. *Energy for Sustainable Development*, 17(2). 95–105. doi:10.1016/j.esd.2012.07.002.

Sheth, J. N., Sethia, N. K. and Srinivas, S. (2010) 'Mindful consumption: a customer-centric approach to sustainability'. *Journal of the Academy of Marketing Science*, 39(1). 21–39. doi:10.1007/s11747-010-0216-3.

Sikkema, R., Steiner, M., Junginger, M., Hiegl, W., Hansen, M. T. and Faaij, A. (2011) 'The European wood pellet markets: current status and prospects for 2020'. *Biofuels, Bioproducts and Biorefining*, 5(3). 250–78. doi:10.1002/bbb.277.

Smil, V. (1994) *Energy in World History*. Westview Press, Boulder.

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., et al. (2007) 'Agriculture'. *Climate Change 2007: Mitigation. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* Cambridge University Press, Cambridhge, UK & New York, NY, USA.

Söderenergi (2009) 'Stormskadad rundved från Frankrike till svenska energiverk ("Storm-damaged roundwood to Swedish energy plants")'. *Press Release*, 8 December. http://www.mynewsdesk.com/se/pressroom/soderenergi_ab/pressreleases/download/resource_attached_pdf_document/351256.

Statistics Norway (2013) *District Heating 2012*. http://www.ssb.no/en/fjernvarme.

Swedish Board of Agriculture (2011) *Energigräs - En Kunskapssammanställning ('Energy Grasses - a Review of Available Knowledge')*. http://www2.jordbruksverket.se/webdav/files/SJV/trycksaker/Pdf_ovrigt/ovr254.pdf.

Swedish Civil Contingencies Agency (2009) *Faller En - Faller Då Alla? ('If One Falls, Do All Fall?')*. https://www.msb.se/RibData/Filer/pdf/24573.pdf.

Swedish District Heating Association (2013) *Statistik Fjärrvärme - Tillförd Energi ('District Heating Statistics - Fuel Input')*. http://www.svenskfjarrvarme.se/Statistik--Pris/Fjarrvarme/Energitillforsel/.

Swedish Energy Agency (2013) *Bränsleforskning: Avfall ('Fuel Research: Waste')*. http://www.energimyndigheten.se/sv/Forskning/Bransleforskning/tillforsel/Avfall/.

Swedish Energy Agency (2012a) *Hållbara Biodrivmedel Och Flytande Biobränslen under 2011 ('Sustainable Biofuels and Bioliquids in 2011')*. ET 2012:12. Swedish Energy Agency, Eskilstuna.

Swedish Energy Agency (2012b) *Översiktlig Risk- Och Sårbarhetsanalys Över Energisektorn I Sverige År 2012 ('Overview Analysis of Risks and Vulnerabilities in the Swedish Energy Sector 2012')*. ER 2012:23. Swedish Energy Agency, Eskilstuna. http://213.115.22.116/System/DownloadResource.ashx?p=Energimyndigheten&rl=default:/Resources/Permanent/Static/2ff553d294584cc298e9575557a2d5ba/ER%202012_23_w.pdf.

Swedish Energy Agency (2009) *Extrema Väderhändelser Och Klimatförändringens Effekter På Energisystemet ('Extreme Weather Events and the Impact of Climate Change on the Energy System')*. ER 2009:33. Swedish Energy Agency, Eskilstuna. http://webbshop.cm.se/System/DownloadResource.ashx?p=Energimyndigheten&rl=default:/Resources/Permanent/Static/b4a6498aadd047f1ab8dfef0ea2fa339/ER2009_33W.pdf.

Swedish Energy Agency (2006) *Stormen Gudrun: Vad Kan vi Lära Av Naturkatastrofen 2005 ('The Storm Gudrun, What Can We Learn from the Natural Disaster of 2005?')*. http://webbshop.cm.se/System/DownloadResource.ashx?p=Energimyndigheten&rl=default:/Resources/Permanent/Static/7b2c2ddb901249d6bf699438460e9f45/ET2006_02wlu.pdf.

Swedish Energy Markets Inspectorate (2012) *Uppvärmning I Sverige 2012 ('Heating in Sweden 2012')*. EI R2012:09. Swedish Energy Markets Inspectorate, Eskilstuna. http://www.ei.se/Documents/Publikationer/rapporter_och_pm/Rapporter%202012/Uppvarmning_i_sverige_EIR_2012_09.pdf.

Swedish EPA (2012) *Avfall I Sverige 2010 ('Waste in Sweden 2010')*. Swedish Environmental Protection Agency. http://www.naturvardsverket.se/Documents/publikationer6400/978-91-620-6520-1.pdf.

Swedish Forest Agency (2013) *Notified Areas Removal Forest Fuel*. http://www.skogsstyrelsen.se/Myndigheten/Statistik/Amnesomraden/Avverkning-och-virkesmatning/Tabeller--figurer/.

Swedish Forest Agency (2006) *Efter Gudrun: Erfarenheter Av Stormen Och Rekommendationer För Framtiden ('After Gudrun, Experiences from the Storm and Reccomendations for the Future')*. http://www.skogsstyrelsen.se/Global/aga-och-bruka/Skogsbruk/Skador%20på%20skog/stormskog%20gudrun%20ny.pdf.

Swedish Government (2011) *Reply to European Commission Letter ENER C1/FPL/pd D (2011) 102 445 Containing Questions Relating to Sweden's NREAP*. Ref. N2011/1144/E. Ministry of Enterprise, Energy and Communications.

Swedish Government (2009) *En sammanhållen klimat- och energipolitik - Klimat*. Prop. 2008/09:162. Stockholm. http://www.regeringen.se/sb/d/11547/a/122778.

Swedish Government (2007) *Sverige inför klimatförändringarna - hot och möjligheter*. SOU 2007:60. http://www.regeringen.se/sb/d/8704/a/89334.

Sycon (1999) *Från Pinne till Panna - Ekonomi, Kvalitet Och Miljöpåverkan Vid Hantering Av Trädbränsle*. Swedish District Heating Association.

http://www.svenskfjarrvarme.se/Global/Rapporter%20och%20dokument%20INTE%20Fjärrsyn/Ovriga_rapporter/Energitillforsel_och_Produktion/Fran_pinne_till_panna_1999_13.pdf.

The Danish Government (2008) *Danish Strategy for Adaptation to a Changing Climate*. Danish Energy Agency, Copenhagen. http://denmark.dk/en/green-living/strategies-and-policies/.

The Swedish Association of Road Transport Companies (2011) *En Vecka Utan Lastbilar ('A Week without Lorries')*. http://www.akeri.se/sites/default/files/uploaded_files/evul_rapport_2011.pdf.

Thorsteinsson, T. and Björnsson, H. (2012) *Climate Change and Energy Systems: Impacts, Risks and Adaptation in the Nordic and Baltic Countries*. TemaNord, 2011:502. Nordic Council of Ministers, Copenhagen, Denmark.

Tol, R. S. J. (2005) 'Adaptation and mitigation: trade-offs in substance and methods'. *Environmental Science & Policy*, 8(6). 572–78. doi:10.1016/j.envsci.2005.06.011.

Trømborg, E. (2011) *IEA Bioenergy Task 40 – Country Report 2011 for Norway*. IEA Bioenergy Task 40 Sustainable International Bioenergy Trade. http://www.bioenergytrade.org/downloads/iea-task-40-country-report-2011-norway.pdf.

Trømborg, E., Ranta, T., Schweinle, J., Solberg, B., Skjevrak, G. and Tiffany, D. G. (2013) 'Economic sustainability for wood pellets production – A comparative study between Finland, Germany, Norway, Sweden and the US'. *Biomass and Bioenergy*, . doi:10.1016/j.biombioe.2013.01.030.

UNEP and WMO (2011) *Integrated Assessment of Black Carbon and Tropospheric Ozone*. United Nations Environment Programme, Nairobi.

US DOE (2013) *U.S. Energy Sector Vulnerabilities to Climate Change and Extreme Weather*. DOE/PI-0013. US Department of Energy. http://energy.gov/sites/prod/files/2013/07/f2/20130716-Energy%20Sector%20Vulnerabilities%20Report.pdf.

US EIA (2013) *EIA International Energy Statistics*. US Energy Information Administration. http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm.

US EIA (2012) *Country Analysis Briefs: Brazil*. US Energy Information Administration. http://www.eia.gov/cabs/brazil/Full.html.

US EPA (2013) *U.S. EPA Region 5 Regional Climate Change Adaptation Implementation Plan Draft: September 18, 2013*. http://epa.gov/climatechange/Downloads/impacts-adaptation/region-5-plan.pdf.

Valente, C., Hillring, B. G. and Solberg, B. (2012) 'Greenhouse Gas Emissions, Energy Use, and Costs–Case Studies of Wood Fuel Supply Chains in Scandinavia'. *International Journal of Forest Engineering*, 23(2).

Van Dam, J., Faaij, A. P. C., Hilbert, J., Petruzzi, H. and Turkenburg, W. C. (2009) 'Large-scale bioenergy production from soybeans and switchgrass in Argentina: Part B. Environmental and socioeconomic impacts on a regional level'. *Renewable and Sustainable Energy Reviews*, 13(8). 1679–1709.

Verchot (2007) 'Climate Change: Linking Adaptation and Mitigation through Agroforestry.' *Mitigation and Adaptation Strategies for Global Change*, 12(5). 17.

Verheyen, R. (2005) *Climate Change Damage And International Law: Prevention Duties And State Responsibility*. Martinus Nijhoff Publishers.

Verhoest, C. and Ryckmans, Y. (2012) *Industrial Wood Pellets Report*. Pellcert. http://www.enplus-pellets.eu/wp-content/uploads/2012/04/Industrial-pellets-report_PellCert_2012_secured.pdf.

Westberg, C. J. and Johnson, F. X. (2013) *The Path Not yet Taken: Bilateral Agreements to Promote Sustainable Biofuels under the EU Renewable Energy Directive*. Stockholm Environment Institute, Stockholm, Sweden. http://www.sei-international.org/publications?pid=2295.

Williams, D. W. and Liebhold, A. M. (2002) 'Climate change and the outbreak ranges of two North American bark beetles'. *Agricultural and Forest Entomology*, 4(2). 87–99.

Wittrup, S. (2013) 'Hvert tredje forbrændingsanlæg fylder udenlandsk affald i ovnen'. *Ingeniøren*, 1 March. http://ing.dk/artikel/hvert-tredje-forbraendingsanlaeg-fylder-udenlandsk-affald-i-ovnen-136793.

Zulu, L. C. and Richardson, R. B. (2013) 'Charcoal, livelihoods, and poverty reduction: Evidence from sub-Saharan Africa'. *Energy for Sustainable Development*, 17(2). 127–37. doi:10.1016/j.esd.2012.07.007.

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