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Trends and perspectives in bioenergy supply in Denmark

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Introduction

Energy security and environmental protection have been the objectives of Danish energy policy over the last few decades.

Energy security was the main driving force for several years after the energy crisis of 1973–4. The idea was to make Denmark less dependent on foreign energy, especially imported oil, by adopting multiple energy sources, especially natural gas, and developing new "alternative" energy sources.

Support programmes and tax incentives were launched to promote the development of renewable energy sources, including bioenergy, wind power and CHP, and of systems to increase energy efficiency and improve supply security for Denmark's own oil and gas.

In bioenergy, the most important factor was a political agreement in 1993 which obliged large power plants to burn 1.2 million t/y of straw and 0.2 million t/y of wood before 2000. This was followed by a decision to convert a number of district heating plants to biofuels and CHP.

In the past few years the political focus has shifted towards opening up the natural gas and power markets as part of Denmark's transition to a free market within the European Union. Support for energy R&D has been much reduced since the end of 2001.

Since the 1992 Rio "Earth Summit", however, growing concern for the global environment has replaced the old agenda of supply security with a new mandate to maintain and enlarge Denmark's role as a pioneer in sustainable development.

As a result, Danish commitment to the Kyoto Protocol has become a strong driving force for energy and environmental policy, resulting in various energy plans with specific targets for greenhouse gas reductions and ways of reaching these targets. In support of this, the Danish Parliament has decided that no new coal-fired power plants will be built. Parliament has also decided that nuclear fission, which by its nature is CO_2-neutral, will not be used for power production in Denmark.

Bioenergy

Danish energy production based on biomass from agriculture and forestry, including biogas, made up around 45% of the country's total renewable energy production in 2001 (Table 2). Straw and firewood are the most important biofuels, followed by industrial wood waste.

Wood fuel in Denmark is available as industrial wood waste (raw or as wood pellets), forest chips, firewood and a very small amount of coppice willow from short-rotation forestry. Firewood, and to an increasing extent wood pellets, are mainly used to heat private houses. Most industrial wood waste is used for industrial heating, while wood chips are primarily used in CHP plants. Wood as an energy resource contributes 25.5 PJ (Table 2), equivalent to approximately 0.6 million tones of oil. Table 2 illustrates the distribution among the individual wood fuels, but does not include wood waste in the form of broken or worn-out furniture, paper etc.

Table 2. Bioenergy production from agriculture and forestry (2001)

	Fuel type	Resource contribution (PJ)
Non-wood	Straw	13.7
	Urban waste	33.0
	Biogas	3.0
Wood	Firewood	12.6
	Industrial wood waste	7.2
	Wood chips	3.2 (6.5 in 2002)
	Wood pellets	2.5 (4 in 2002)
Total		75.2 (approximately 80.0 in 2002)

Note: 1 PJ is equivalent to the lower calorific value of 23,810 t of oil. Source: Energistatistik 2001; Danish Energy Agency.

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Since the late 1990s there has been an increasing international trade in wood chips and wood pellets, and Denmark now imports substantial amounts of these. Total Danish consumption of wood is approximately 8 million t/y, of which 6 million t/y is imported and Danish forests supply the rest. The intention is that most of this wood ends up as fuel, either directly or after having been used for other purposes first. In the latter case, however, national statistics class the wood simply as "waste", making it hard to distinguish from other kinds of waste.
Under the 1993 "bioenergy agreement" two new CHP plants started production in 2002, one using 200,000 t/y of wood chips and the other 150,000 t/y of straw.
Only a very small part of Denmark's approximately 30 million t/y of animal manure is currently used to produce biogas. A number of relatively large on-farm biogas plants started production in 2002, the last centralised biogas plant having been put into production in 1998. Changes in subsidies for green electricity produced on new plants built after 2002 have put an economic halt to new biogas plants. However, the recent agreement for subsidies for electricity from new biogas plants has opened up for a number of new biogas initiatives.

The Danish bioenergy industry

The bioenergy technologies currently most developed in Denmark are those for biogas production (Table 3). The basic raw material is animal manure, of which Danish farms produce 34.1 million t/y (including 27.0 million t/y of slurry).
Green Farm Energy A/S has developed an advanced biogas plant that runs on manure, supplemented with other agricultural waste products containing less water, such as straw or future energy crops. The plant also removes nitrogen and phosphate from its waste stream, thus solving the problem of how to stop these two nutrients polluting watercourses.
Another novel concept is to use manure and wheat straw in a combined process that yields bioethanol as well as biogas (Chapter 6.4).
Reference 2 also lists a large number of manufacturers and suppliers of wood-fired boilers.

Rapeseed is the only oilseed crop currently grown by Danish farmers. Several mills are now refining cold-pressed rapeseed oil so that it can be used in heating systems.
The potential for using rapeseed oil as a source of biodiesel has not yet been fully explored in Denmark. Emmelev Mølle is the only producer of rapeseed oil methyl esters (RME, or biodiesel). Due to lack of national tax exemptions for liquid biofuels most of this is exported to Sweden and Germany instead of being used in Denmark.
When biomass such as wood and straw burns, a number of chemical processes convert the carbonaceous material into a mixture of gases which are subsequently combusted. It is possible to use the energy contained in the biomass more efficiently by separating the processes of gasification and combustion. New two-stage gasifier (Table 3) plants use fixed-bed or fluidised-bed reactors to produce a mixture of carbon monoxide and hydrogen, which can then be burned either alone or combined with gas from other sources. A challenge for gasification technology is to remove the corrosive ash created by the high levels of chloride and potassium present in plant biomass or high molecular tars and hydrocarbons from the pyrolysis and gasification process. Ashes from biomass only, are recycled to agriculture and forestry.
Denmark's forest area of approximately 0.5 million ha supplies an increasing amount of firewood and forest chips. In the light of the Government's plan to double this area of forest, Denmark's total wood fuel resources will increase in the years to come. Afforestation takes place on agricultural land and will therefore result in a

Table 3. Bioenergy industry in Denmark.

Company	Technology type
Bioscan A/S	Biogas
GasCon	Biogas
Gosmer Smeden	On-farm biogas
Dansk Biogas A/S	Biogas
Green Farm Energy A/S	Biogas
Lundsby Bioenergi	Biogas
Emmelev Mølle	RME, biodiesel
Cowi with DTU / Vølund	Gasification
Danish Fluid Bed Technology	Gasification
Hollensen	Gasification
Carbona / Skanska	Gasification

Source: this manuscript.

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proportional decrease in the straw and energy crop potential.

Environment

As a small country, Denmark is heavily influenced by international agreements on energy and environmental issues, and the increasing internationalisation of markets. To avoid being swamped by outside forces, Denmark must therefore secure the greatest possible influence in international affairs concerning energy and the environment. This will help the country achieve its goals and create the best conditions for its domestic environment and economy.

The EU Directive has set as an “indicative goal” that by 2010, 29% of Denmark’s electricity should be produced from renewable sources, including biomass and biowaste. Agriculture and forestry provides 47 PJ in 2002 and urban waste is predicted to contribute with constant amount of 33 PJ.

Forest chips result from first and second thinning, from harvesting over-mature and partly-dying pine plantations, and from tops following clear-cutting. Wood chips have become even more important as a fuel over the two last decades, and their significance is underlined by the Danish national obligation to reduce CO_2 emissions.

The production of biogas from manure will also affect the environment. In particular, the ability of large on-farm biogas plants to remove nitrogen and phosphate will reduce the quantities of these nutrients polluting watercourses and coastal areas. Instead, farmers will be able to recycle the nitrogen and phosphate for crop production.

What can be done?

In previous decades Danish energy policy was marked by strong public involvement at every stage and a pioneering approach towards global sustainable development. This has been replaced by a new balance between general economic growth and the development of energy technology. The priority in energy policy is now liberalisation, with the aim of meeting Denmark’s international environmental commitments and at the same time expanding the economy.

The Kyoto Protocol’s flexible mechanism shall be used as an integrated part of the Danish climate change policy in order to fulfil the Kyoto commitment. The Danish Government has started a process in order to analyse how climate target in Denmark is to be obtained most cost effectively. The use of the Mechanism plays a central role in the planning of the process. The planning is carried out in co-operation between the Ministry of Finance, Environment, Foreign Affairs, Taxation and the Ministry of Economic and Business Affairs (Energy) to assist the energy industry in implementation of the JI and the CDM tools. The JI projects are expected to be launched primarily in the Eastern Europe while CDM projects are to be carried out in the developing countries.

Future bioenergy resources

Danish bioenergy from agriculture and forestry is currently based mainly on waste materials such as straw, waste from the wood industry and forest thinnings. Under the revised bioenergy agreement, by the end of 2004 the electricity companies are obliged to use 1.4 million t/y of biomass, including 930,000 t/y of straw. Agriculture, forestry and the wood industry can easily supply these quantities of biomass.

Given the present political strategies for energy and the environment, it is difficult to foresee any substantial increase in the demand for solid biofuels from agriculture beyond 2004. At present there is no tax exemptions or subsidies for liquid biofuels and the future national

Table 4. Estimated biomass resources from agriculture for energy purposes, 2015. Based on Gylling et al. 2001.

		Scenario			
	Unit	2000 Current	2015 Reference	2015 Environmental	2015 Market
Total straw production	tonne	6,484,000	5,857,000	4,840,000	6,758,000
Available straw for energy purposes	tonne	2,663,000	2,445,000	1,414,000	3,494,000
	PJ	37.4	34.3	19.8	49.0
Available area for energy crops	ha	186,000	168,800	160,000*	85,000
Potential energy production	PJ	27.9	25.3	24.0	12.8
Total potential straw and energy crops	PJ	65.3	59.6	43.8	61.8

* 85,000 hectares ESA – set-aside. + 75,000 hectares set-aside

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politics is not yet known. If demand were to increase, however, current biofuel resources would soon be fully utilised. The logical next step would be to grow dedicated energy crops, though under the present Common Agricultural Policy (CAP) this would only be economic on set-aside land.

A study by the Danish Research Institute of Food Economics estimates potential production of biomass for energy in the range 44–62 PJ/y, depending on developments in the framework conditions for Danish agriculture (Table 4).

The study outlines three different agricultural scenarios up to 2015. The first scenario is a reference case in which current trends are simply extrapolated. The "environmental" scenario proposes a higher degree of environmental awareness, while the "market" scenario imagines a future in which agriculture becomes more competitive in economic terms.

The estimate of total biomass available for energy production is based on the assumption that set-aside land is used to grow a mixture of energy crops; whole crop wheat and triticale, plus willow coppice. The average annual yield is estimated at 9 t/ha of dry matter. The reference and market scenarios estimate the amount of energy available from biomass at 59.6 PJ and 61.8 PJ respectively, though the market scenario includes about 40% more straw because grain production is higher. The environmental scenario yields only 43.8 PJ of bioenergy, mainly because grain production is lower.

Straw and energy crops (whole crop grain, willow and *Miscantus*) are to a large extent interchangeable in large multi-fuel burners (Gylling 2001), but differences in storage characteristics need to be taken into account when setting up the biofuel production chain in order to secure an economic efficient all year supply.

Fuel pellets seem to be an expanding market. Wood pellets currently account for almost the entire market, but a recent Danish study (Nikolaisen 2002) found that fuel pellets made from mixed biomass sources can provide the same quality as wood pellets, as long as the right ingredients and additives are used.

Most firewood comes from thinning and clear-cutting of hardwood stands, in the form of smaller trees, tops and branches. Official statistics show that Danish forestry produces approximately 450,000 m^3/y (solid volume) of firewood, but this does not take into account firewood taken from gardens and parks.

There have been three assessments of forest fuel resources in Denmark. Table 5 shows predictions for fuelwood resources (forest chips plus forest firewood) taken from the most recent of these assessments (Nord-Larsen & Heding, 2003), which extrapolates from the current national forest inventory using models for forest growth and yield. The figures cover three ten-year periods (2000–2009, 2010–2019 and 2020–2029), each under three scenarios in which utilisation of forest resources becomes progressively more intense.

The three scenarios are:

1. Whole-tree chips from early thinning and from final felling of over-mature pine.
2. In addition to Scenario 1, forest chips from branches and tops harvested during final felling.
3. In addition to Scenario 2, forest chips from tops and branches harvested during later thinning.

Under all three scenarios, potential production of forest chips exceeds the current figure by a factor of 1.5–2.

Research

Research on wood fuels has changed direction over the years. In the 1980s the focus was on harvesting techniques and long-term storage. In the 1990s emphasis changed to the physical characterisation of wood chips, their storage properties, and how to optimise silvicultural regimes to produce more chipping material.

Current research topics include reducing the harmful effects of mould and understanding the nutrient balances associated with intensive chip harvesting from

Table 5. Danish fuel-wood resources for three scenarios over the next 30 years. Source: Nord-Larsen & Heding, 2003.

		Time period		
Scenario	Fuel-wood production	2000–2009	2010–2019	2020–2029
1	Volume (million m^3 solid volume/y)	0.9–1.3	0.9–1.3	0.9–1.3
	Energy (PJ/y)	8–11	8–11	8–11
2	Volume (million m^3 solid volume/y)	1.1–1.5	1.1–1.5	1.2–1.6
	Energy (PJ/y)	9–12	9–12	9–13
3	Volume (million m^3 solid volume/y)	1.3–1.7	1.3–1.7	1.4–1.8
	Energy (PJ/y)	11–14	9–14	9–15

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whole trees. More use of forest fuels means more wood ash, and another research topic is how ash can be returned to the forest floor – a disposal route that is hindered by current regulations. Yet another research area is how to improve the performance of the wood fuel supply chain, which at the moment is very tight.

Future R&D should also aim to create new plant strains with high energy contents and other characteristics to make them suitable as biofuels. New chemical and biological transformations, as well as improvements to existing separation and concentration processes, are needed for the production of bioethanol, biodiesel and hydrogen and other biofuels.

Danish farmers will continue to grow rapeseed if for no other reason than its advantages in crop rotation, so a significant and predictable amount of rapeseed oil can be expected. To make it ideal for biodiesel (RME) production, however, rapeseed needs to be developed so that its oil is more resistant to high temperatures and oxidation. Other technical advances would allow rapeseed to be used to create biolubricants as well.

To meet these goals a multitude of instruments are used by Danish R&D connecting public and private sector. The funding is provided by the public, national as well as EU and for some specialized issues by DOE. Private investors show increasing interest in this field to develop local industry which address European agrofuels challenges, because the Danish market is limited in size.