Energy scenarios
for 2020, 2035 and 2050

Summary
This paper describes four scenarios for Denmark's future energy supply up to 2050.

"Scenarios" are technically consistent models of the future energy supply, including transport, which meet specified political targets. As the whole system is included in the scenarios, these also describe the relationship between the various sub sectors of the energy system. This ensures consistency between the individual sector analyses in terms of resource use and energy conversion.

All of the scenarios meet the vision of a fossil fuel independent energy system by 2050, as well as the government's goal of fossil fuel independent electricity and heating by 2035. The paper also describes a scenario with fossil energy use. The purpose of the scenarios is to describe the scope available for Danish energy supply in the future. The scenarios form a common background for the analyses that were launched with the energy agreement of 22 March 2012.

The scenarios shed light on the technical possibilities available for designing the future Danish energy system under given assumptions, and they describe some of the challenges encountered by a transition to fossil fuel independence, including highlighting critical parameters. The scenarios can also to some extent indicate when important decisions need to be made.

The scenarios should not be understood as detailed forecasts or final answers about the actual or preferred design of the future energy system. Neither do the scenarios include any specific recommendations on which instruments are needed to realise the scenarios.

The net energy consumption in the scenarios has been calculated on the basis of a consumption model of energy consumption in 2035 and 2050 analysed by quality of energy at three different levels of energy savings (moderate, large and extra-large savings). The following is included: electricity, district heating, process heating, individual heating, and energy for transport (including aviation and domestic shipping). The oil and gas-extraction sector has been excluded from the analyses. The same level of energy services has been assumed for all scenarios; that is, the same industrial production, the same heated area, the same transport performance, etc. has been assumed for all scenarios. It is therefore also implicitly assumed that the technologies, which vary from scenario to scenario, are each other's perfect substitute, so that, for example, an electric car provides the same utility value as a car with a combustion engine.

The energy production in the scenarios has been calculated on the basis of a simulation model, which is used examine the system operation on a time-scale down to one hour in order to determine the necessary capacities and the annual fuel consumption as well as the costs of operation and maintenance. Annuitised investment costs have been used to represent capital cost. Technology data is from the most recently published technology catalogues, which include assessments of expected technological developments up to 2050. The trend in fuel prices is assumed to be in line with the three scenarios in World Energy Outlook 2013 (Current Policies Scenario, New Policies Scenario, 450 Scenario).

Description of the scenarios:

- The wind scenario is designed to use bioenergy corresponding more or less to what Denmark itself an supply, i.e. around 250 PJ. This does not mean the bioenergy necessarily has to be Danish, but that it can be supplied from Denmark. This requires massive electrification within transport, industry and district heating, as well as a considerable expansion with offshore wind turbines. In order to keep the consumption of bioenergy low, hydrogen is produced and used to upgrade biomass and biogas to make it last longer.

- The biomass scenario is designed to an annual bioenergy consumption of around 450 PJ. This en tails a certain volume of net biomass imports in normal years (around 200 PJ) No hydrogen is involved.

- The Bio+ scenario entails a fuel-based system similar to that we have today, with the only exception that coal, oil and natural gas are replaced by bioenergy. Fuel consumption will be around 700 PJ. No hydrogen is involved.

- The hydrogen scenario is designed to simulate very small bioenergy consumption (under 200 PJ). This entails considerable use of hydrogen and considerably more wind power than in the wind scenario.

- The fossil-fuel scenario outlines a theoretical situation in which fossil fuels are used and all policy targets are disregarded. The fossil-fuel scenario illustrates an alternative that focusses mainly on 'lowest possible costs'.

Table 1.1 summarises the main figures from the four scenarios in 2050, and table 1.2 shows the corresponding figures for 2035. Fuel consumption is inclusive of any biomass conversion and transport losses abroad.

Scenario	Wind	Biomass	Bio+	Hydrogen	Fossil fuels
Fuel consumption	255 PJ	443 PJ	710 PJ	192 PJ	483 PJ
Degree of self-sufficiency	104%	79%	58%	116%	(*)
Gross energy consumption	575 PJ	590 PJ	674 PJ	562 PJ	546 PJ

Table 1.1 Key figures from the scenario calculations for 2050. (*) depending on Danish fossil-fuel production in 2050.

Scenario	Wind	Biomass	Bio+	Hydrogen	Fossil fuels
Fuel consumption	458 PJ	526 PJ	631 PJ	443 PJ	680 PJ
Degree of self-sufficiency	74%	68%	57%	77%	(*)
Gross energy consumption	594 PJ	606 PJ	634 PJ	590 PJ	653 PJ

Table 1.2 Key figures from the scenario calculations for 2035. (*) depending on Danish fossil-fuel production in 2035.

Important main conclusions of the scenario analyses:
It is possible technically to design different energy systems which all meet the vision of fossil fuel independence. The technologies already exist, although some of them need to be further developed in terms of price, efficiency and performance capability.

Bioenergy is a limited resource. Because Denmark is a small country, we have a choice between establishing a fuel-based system with large imports of biomass and an electricity-based system with limited use of bioenergy at a level around that which Denmark can supply itself. With 2050 as the target year for fossil fuel independence, Denmark will probably have to make a decision on this soon after 2020, as the large transitions required, such as expansion of wind power and infrastructure, take time. The choice depends, in particular, on the desired degree of fuel supply security.

To some extent, a system based on wind power can use more bioenergy than it was designed for if, for example, there is a year with low biomass prices. Furthermore, to some extent, a system based on fuel can use less bioenergy than it was designed for if, for example, there is a year with high biomass prices. Thus, there is some leeway with regard to reacting to changing prices. However, it is not possible to change from a fuel-based to wind power-based system (or the other way around) from one year to the other.

A wind power-based, fully electrified system will have good fuel supply security but will have problems ensuring a reliable electricity supply, while a bioenergy-based system will have problems ensuring a reliable fuel supply. In a wind power-based system, reliable electricity supply can be ensured through a combination of low-investment, fast-regulating gas engines/gas turbines that are not given much operating time, and more electrical interconnectors to neighbouring countries. The scenarios have been designed to meet the same requirements for reliable electricity supply. In a bioenergy-based system, fuel supply security can be ensured by establishing a system that can switch to fossil fuels if the supply of bioenergy fails, or if biomass becomes very expensive. Naturally, choosing such a strategy does not realise the vision of a system free of fossil fuels.

The calculations indicate that the costs of a fossil fuel independent energy supply in 2050 are around DKK 136-159 billion excluding taxes and fees, of which around half is attributable to transport. This amount includes investments, operating costs, fuel (including distribution), CO2, costs of energy savings, propulsion systems for all types of transport, energy-producing facilities in electricity, district heating, process and individual heating. The costs of a scenario have been calculated bottom-up as the sum of annuitised investments at an interest rate of 4%, operating costs, and fuel costs.

The annual costs in the fossil-fuel scenario in 2050 are around DKK 6 billion lower (around 5%) than the cheapest fossil fuel independent scenario and around DKK 29 billion lower (around 20%) than the most expensive fossil fuel independent scenario (with a CO2 price of DKK 245/tonne). This is due, in particular, to the assumption of a coal price at a considerably lower level than for all other fuels. There are large costs associated, in particular, with the production of biogas and with upgrading biogas in all of the fossil fuel independent scenarios. A large part of the costs in the four fossil fuel independent scenarios and the fossil fuel scenario are common for the scenarios. This includes, for example, costs of savings, waste incineration, district heating grids, gas grids, as well as a proportion of the electricity-grid costs, propulsion systems for transport, wind power, and the other energy plants.

All cost calculations are associated with significant uncertainty, because future fuel prices, electricity prices and technology costs, including costs of energy savings, are very uncertain. The technology catalogues typically expect a decreasing prices of RE technologies in the long term relative to fossil-fuel technologies. The extra costs per unit of RE are therefore expected to be higher in the medium term (2020-2035) than in the long term (2035-2050). However, there will be a smaller total volume of RE in the short and medium term than in the long term.

Costs have been calculated in constant 2011-12 prices less taxes, fees and subsidies. The scenario calculations do not make recommendations as to which instruments (taxes/fees, subsidies and regulation) will be necessary in order to realise the transition to fossil fuel independence. Thus, instrument costs, tax distortions and net-tax factors are not included in the scenarios. Possible structural changes in energy demand and the associated costs hereof in connection with a transition to fossil fuel independence are not included either, cf. the overall assumption of an unchanged energy service level across all scenarios.

With the technology assumptions used, wind power has relatively low production costs per kWh in 2035 and 2050. Nonetheless, the wind scenario has slightly higher total costs than the biomass scenario. This is due to derived costs of a large wind expansion: extra grid costs, reserve capacity at low-wind production, and the circumstance that the export price of electricity at high-wind production is likely to be lower than average, and that the import price for electricity at low-wind production is likely to be higher than average. However, it only takes a 35% increase in the price of biomass for the wind and biomass scenarios to be equal. Similarly, a halving of the electricity grid costs will also make the wind and biomass scenarios equal.

Sensitivity to fuel prices is lowest in the wind and hydrogen scenario and highest in the biomass and bio+ scenarios. The bio+ scenario is especially sensitive to the price of imported biofuels.
With the technology assumptions used, electric vehicles and to a certain extent expanding wind power will be economically beneficial. This has therefore also been incorporated in the fossil scenario. The arrival, by no later than around 2030, of electric cars able to meet approximately the same performance as traditional cars in terms of range etc. is a key assumption for all scenarios, except for the bio+ scenario. The omission of electric cars from the bio+ scenario, together with the assumptions applied, is the main reason why this scenario has the highest costs of all the scenarios.

A fossil fuel independent transport sector will demand very large amounts of bioenergy in 2050. With regard to passenger transport, a part of goods transport, rail transport, etc., this can be overcome by converting to electricity and, to some extent, gas (SNG). This would require establishing infrastructure and converting the car fleet. Such a transition cannot be commenced in 2049 but has to be commenced before 2035 in order to take account of the technical lifespan of vehicles, technological developments, even distribution of investments, etc.
More or less the same applies to conversion to RE in process heating as applies to transport. Here, however, the issue is not as much infrastructure as it is the establishment of plants based on biomass and electricity.

Fuel factories to produce the biofuels to power aircraft, lorries, etc. can be located in Denmark or abroad. If biofuels are produced extensively in Denmark, there will be a potentially large amount of surplus heat, which could be exploited. If the biofuels are imported, this opportunity will not be available. There has been no assessment of the competitive situation for Danish biofuel production compared to imports. In addition to opportunities to sell heating, this competition depends on regional differences in electricity prices and biomass prices, for example. In the case of a Danish biofuel production, the establishment of an infrastructure for biofuel factories will also have to be commenced in good time before 2050, and the timing of establishment of these factories will be of great significance for the design of the electricity and district heating system. However, there is no need for a decision on this before 2020.

In the wind scenario and in the hydrogen scenario, massive electrification of the energy system is required. This entails expanding the electricity grid, on the supply as well as on the demand side. Part of this expansion consists of units to stabilise voltage, frequency, etc., as electricity generation will primarily be based on wind power. This same applies to the biomass scenario, although to a lesser extent, while the electricity grid in the bio+ scenario resembles what we already have today.

The wind power capacity in the wind scenario will have to be expanded by an average of what corresponds to a 400MW offshore wind farm annually from 2020 to 2050. Furthermore, obsolete wind turbines will have to be replaced. In the hydrogen scenario, expansion will have to take place at an even faster rate. In the biomass scenario, the expansion rate corresponds approximately to one 400MW farm every three years.

The amount of (synthetic) natural gas in 2050 in the scenarios is limited to what can be supplied from biogas plants, possibly upgraded with hydrogen. This means that the use of gas must be targeted at uses with the greatest utility value: transport, industry and fast-regulating electricity production plants. The existing gas grid and gas storage facilities will presumably make up an appropriate infrastructure for transportation of fuel and for ensuring security of supply in 2050. Additional gas will exist as intermediate products at fuel factories, however these will not necessarily enter the gas grid. Natural gas could be used as a buffer in years with low wind speeds or in dry years. Such a buffer would be necessary to ensure the security of supply. Extra SNG could be bought from the market (if SNG is traded at that time). However, SNG is around twice as expensive as natural gas. The use of extra natural gas could be compensated for through extra fossil fuel independent production based on wind power, for example.

All of the scenarios assume ‘large’ energy savings. A sensitivity calculation indicates that extra-large energy savings will lead to an increase in total costs in the wind scenario. However, there is large uncertainty about the costs of savings. If these costs are one-third lower, the total system costs with large and extra-large savings, respectively, will be equal.

All scenarios (except the fossil scenario) assume 2000 MW photovoltaic solar modules in 2050. Up to a certain point, there is a system-related advantage from mixing solar PV and wind power, because of differing production profiles. However, a sensitivity calculation suggests that increasing solar capacity will lead to increasing total costs, because the extra investment costs associated with photovoltaic solar modules are not fully offset by the system-related advantage. However, if photovoltaic solar modules become 30% cheaper than predicted in 2050 (when a more than halving of the price relative to today has already been assumed), solar capacity could be increased somewhat at no extra cost.

The scenarios extensively include heat storage facilities. Heat storage facilities play an important role in the intelligent electricity system for uptake of wind power. Electricity storage in Denmark is not included. The preliminary assessment is that use of the electricity market (including hydropower storage facilities abroad) and flexible electricity consumption are cheaper solutions.