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Published in:
Proceedings of the 4th Dubrovnik Conference on Sustainable Development of Energy, Water and Environmental Systems

Publication date:
2007

Document Version
Publisher's PDF, also known as Version of record

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ABSTRACT

Governments worldwide aim at reducing CO_2 emissions and expanding renewable energy. A key element in achieving such a goal is to use renewable energy in transport such as biofuels. However, efforts to promote single transport technologies and single fuels only represent a partial solution. No single technology can solve the problem of ever increasing CO_2 emissions from transport. Transport must be integrated into energy planning, as electricity and heating. In this paper, a coherent effort to integrate transport into energy planning is proposed, using multiple means promoting sustainable transport.

It is concluded that a 100 per cent renewable energy transport system is possible but is connected to significant challenges in the path towards it. Biomass is a limited resource and it is important to avoid effecting the production. The integration of the transport with the remaining energy system is crucial as is a multi-pronged strategy. Short term solutions have to consider the long term goal. In a short term proposal for 2030 it is concluded that it is possible both to reduce CO_2 emissions substantially and, at the same time, gain socio-economic benefits. Biofuels is not able to solve the problems within the transport sector but plays an important role in combination with other technologies.

1. INTRODUCTION

The global focus on the resource consumptions of transport is increasing these years due to two main factors. First, when considering renewable energy and CO_2 emissions, electricity and heating have traditionally been in focus. As more and more countries have implemented changes in these sectors, the focus on transport has been intensified. Secondly, transport gains increasing international attention due to its large oil dependency of app. 95 per cent globally. In almost all regions worldwide, the demand for oil is increasing and the transport sector's share of the total oil demand is increasing

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even faster, with a share of app. 50 per cent at the moment [1]. This, in combination with other international geopolitical tensions, has led to substantially increasing oil prices over the last years, with prices above 50$ a barrel since January 2005. In Denmark, the above-mentioned issues are even more evident. Danish energy policies have been successful within electricity and heating where political focus has produced actions and initiatives, i.e. the CO_2 emissions have been declining and the fraction of oil is low in these sectors [2]. In the transport sector, however, this is not the case.

The two main solutions to the problems of the transport sector are 1) to integrate the transport sector into the energy system in energy planning and 2) to increase the amount of renewable energy for transport in the form of electricity or biomass.

The IPCC (Intergovernmental Panel on Climate Change) report from 2007 has increased the focus on renewable energy. In 2003, the European Union was 98 per cent dependent on oil for transport. Recently, the EU countries agreed that 20-30 per cent of their primary energy supply (PES) shall be covered by renewable energy in 2020. 10 per cent of the fuels for transport must be biofuels in 2020. The directive on biofuels from 2003 has set specific targets for the transport sector in the EU member countries [3]. However, the target of 2 per cent biofuels in 2005 was not reached. In a European Commission strategy on biofuels from 2006, emphasis is put on second generation biofuel production for the substitution of oil products [4]. Worldwide, the focus on biofuels has increased recent years, thus biofuels are presently in focus when promoting renewable energy for the energy sector. However, biofuels alone will not be able to solve the problems of the transport sector. The biomass resource is limited. Furthermore, the problems of blind promotion of biofuels are documented by food prices worldwide. It is, therefore, crucial to promote efforts involving other technologies, nationally as well internationally.

In national energy plans, transport has historically been ignored. Focus is on savings and improved efficiency within electricity and heating. This has also been the case of Danish Energy Plans [2]. However, in January 2007, the Danish government suggested a share of 30 per cent renewable energy in 2025 and 10 per cent biofuels in 2020.

Denmark has managed to stabilise PES, which is the same as before the first oil crises in the 70s. The share of oil is much smaller today and 20 per cent of the electricity is wind power. 15 per cent of PES is from renewable energy including biomass and waste. Moreover, energy savings and efficiency improvement have constituted an important part of the policy leading to that 50 per cent of the electricity production originates from CHP. This has only been possible due to an active energy policy [2].

In the same period, the quantity of oil for transport in Denmark has been steadily increasing, since the active policy mentioned above has traditionally excluded transport. The energy consumption of transport has risen from 135 PJ in 1972 to 216 PJ in 2005. It is expected to be 249 PJ in 2030 if no new policies are implemented. This development is symptomatic of the lack of focus on transport. While the consumption and production of electricity and heat have been part of policy-making, the increasing fuel consumption in the transport sector has swallowed part of the efficiency gains. In fig. 1, PES and the transport part of the energy consumption are illustrated for 1972-2005 and for a scenario for 2030. If no further actions are taken the path to a sustainable development in the Danish energy system will be harder and harder to achieve. In the reference for 2030 from the Danish Energy Authority (DEA) this problem is clearly identifiable.

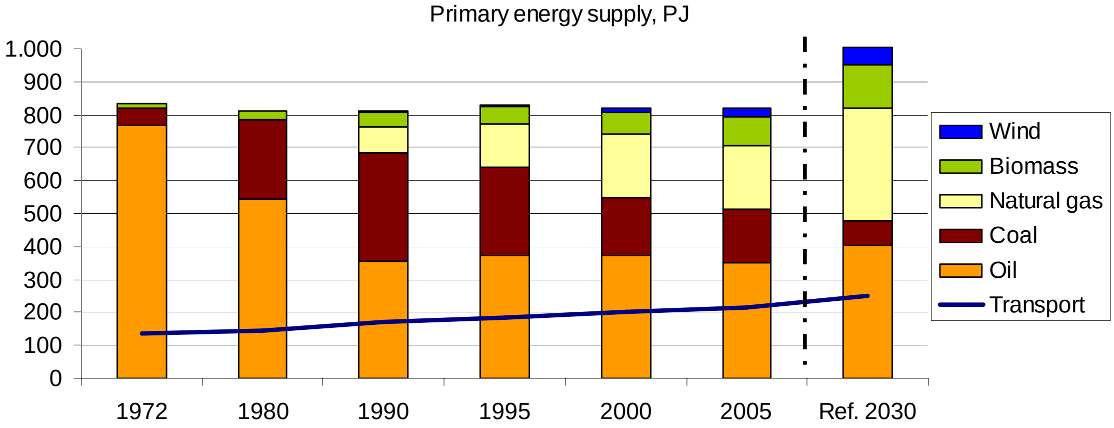

Fig. 1 The Danish primary energy supply and fuel supply for transport from 1972 to 2005 and the reference scenario for 2030.

If the aim is to increase the share of renewable energy in Denmark as such, the transport sector is one of the most important sectors to include in combination with other flexible technologies for energy systems [2]. In other sectors, measures have already been taken to reach this aim. In most analyses of the implementation of transport technologies, though, the various technologies – such as bioethanol, battery electric vehicles, hybrid vehicles, hydrogen vehicles or public transport etc. – are investigated individually. A narrow focus on one technology is not sufficient, as no single technology can point the way to a sustainable development of the transport sector.

In the Danish energy system, coherent studies of electrical, battery, biomass and fuel cell technologies show that the integration of transport technologies into the energy system can give economic benefits of the combined system and decrease fuel consumption and CO_2 emissions. This integration also increases the energy system's ability to integrate fluctuating renewable energy sources such as wind power. [5]

The design of 100 per cent renewable energy systems has to meet especially two major challenges. One challenge is to integrate a high share of intermittent resources into the energy system, especially the electricity supply [6-13]. The other is to include transportation [5]. In this paper proposals are made to help meet both challenges.

Transport's energy consumption must be analysed with the energy system surrounding it and a multi-pronged proposal is necessary in order to achieve a sufficient impact. When integrating transport with renewable energy systems, only coherent analyses of the energy system can reveal whether the measures to increase the renewable energy share of the transport sector are successful. This is the focus of the analyses in this paper. An energy system is proposed for 2030 with 50 per cent renewable energy and a 100 per cent renewable energy system is proposed for 2050.

2 METHODOLOGY

In October 2006, the Danish Prime minister announced that the long-term target for Denmark is 100 per cent independence of fossil fuels and nuclear power. In December 2006, the Danish Association of Engineers (IDA) proposed a plan to achieve such targets in 2050. This paper is based on the results of the IDA Energy Plan 2030. This Energy Plan was the result of the "Energy Year 2006" project, in which 1600 participants in more than 40 seminars discussed and designed a future energy system in Denmark. The framework of these efforts is based on three overall targets:

- To maintain security of energy supply
- To cut CO_2 emissions by 50 per cent by year 2030 compared to the 1990 level
- To create employment and to raise export in the energy industry by a factor 4

The process of designing a future sustainable energy system involved both a creative phase with inputs from a number of experts, and a detailed technical and economic analysis phase. The detailed energy system analysis and the feasibility studies of the overall energy plan were carried out by researchers at Aalborg University, using the energy system analysis model EnergyPLAN [14]. In the technical and economic analysis phase, feed-back on each individual proposal was given. In a forward and back process, each proposal was assessed for a coherent energy system in the IDA Energy Plan. This process made it possible to combine the best expert knowledge with an evaluation of the ability of each proposal to fit into the overall system. Furthermore, it enabled the formulation of an energy system proposal which is technically innovative, energy-efficient in terms of supply and socio-economically feasible [15].

The seminars forming the inputs were divided into seven themes which led to proposals on how each theme could contribute to the three overall targets. One of these themes was transport and mobility. The contributions from the themes involved energy demand side management and energy efficiency within households, industry and transportation. Improved energy conversion technologies with high temperature fuel cells such as SOFCs (Solid oxide fuel cells) and renewable energy sources such as photo voltaic, wind and wave power were included. All proposals were described in relation the 2030 "business as usual" reference from the DEA [16]. These descriptions include technical consequences as well as investment and operation and maintenance costs [17].

The results are detailed energy system designs and energy balances for two energy target years. For 2050, a 100 per cent renewable energy system is proposed and analysed technically. For 2030, a 50 per cent renewable energy system is proposed, emphasising the first important steps on the way. For the first step until 2030, the results include detailed socio-economic feasibility studies and electricity exchange analyses.

This paper presents the methodology and results of a multi-pronged proposal for integrating transport in a 100 per cent renewable energy system. The proposals for a sustainable development in the Danish transport sector are described.

2.1 Analysis methodology

In a parallel process, all proposals were analysed technically in an overall energy system analysis by use of the computer model EnergyPLAN [14]. The model enables the analysis of annual energy supply and demand in hour by hour calculations of the system. Its focus is regulation strategies for the integration of large quantities of intermittent renewable energy sources and CHP (Combined Heat and Power). With the model, it is possible to conduct detailed technical energy system analysis as well as socio-economic feasibility studies and exchange analyses on international electricity markets. In the process of analysing the IDA Energy Plan, the model was improved and expanded to version 7.0. In particular, the analyses of different transport technologies and elements of the economic analyses were improved.

The Danish Energy Authorities' "business as usual" reference for the Danish energy system of 2030 was re-calculated by use of the EnergyPLAN model. Consequently, a common understanding of the reference was established. Subsequent to the forward and back process, all proposals were simulated technically in the model and more proposals were made, improving the energy system imbalances initially caused by the proposals. Following this, the socio-economic feasibility of the energy system was assessed. In this analysis, all production units run on the basis of a business-economic optimisation, i.e. including taxes and prices on the international electricity market. On the basis of the analysis, flexible energy systems were designed with good abilities to balance the electricity supply and demand and to exchange electricity on the international markets.

The socio-economic evaluation of the consequences for Danish society does not include taxes. It is based on assumed fuel costs equal to an oil price of 68$/barrel [17]. The investment and operation costs are based on Danish technology data [18], if available, and if not, based on the input from the "Energy year" experts. An interest rate of 3 per cent is used in the analysis (with a sensitivity of 6 per cent). The environmental costs are not included, apart from CO_2 trade prices of 20 €/ton (with sensitivity of 40 €/ton).

Each individual proposal was analysed technically and a feasibility study was conducted. Since many of the proposals are not independent in nature, such analysis was conducted for each proposal, both in the reference "business as usual" system as well as in the alternative system. In this paper, the proposals of transport and mobility are described thoroughly and the socio-economic consequences of the transport proposals are presented. The technical energy systems analyses and the exchange analysis on international electricity markets are presented in [15].

2.2 Implementation of proposal for a sustainable transport development

In the IDA Energy Plan, a wide range of measures has been proposed and analysed. The measures are different from other suggestions related to transport policy because the plan involves a wide range of technologies and includes both the demand and supply side. Also, it differs from other analyses as its measures have been analysed both in the context of the surrounding energy system and in relation to economics. The following proposals for Denmark are part of the transport theme:

- Passenger transport work (person km) in vehicles, trains and bicycles is stabilised at the 2004 level in 2030.
- The rate of increase in passenger air transport is limited to 30 per cent instead of 50 per cent in the period from 2004 to 2030.
- 20 per cent of the passenger road transport is transferred to trains, ships and bicycles in 2030:
  - ~ 5 per cent transport of goods (ton km) transferred from roads to trains and 5 per cent to ships
  - ~ 5 per cent passenger transport is transferred to trains and 5 per cent to bicycles.
- 30 per cent more energy efficiency in the transport sector compared to the reference situation in 2030 with stable passenger transport at the 2004 level and with a lower increase in air transport.
- 20 per cent biofuels and 20 per cent battery electric vehicles in road transport.

Initiatives within all means of transport have to be taken in order to stabilise the total passenger transport work and achieve the transfers between types of transport and a more efficient transport sector mentioned above. In the sections below, the proposals are operationalised by means of the following considerations and are implemented in steps. The consequences of each proposal and step are listed in table 1.

2.2.1 Constant passenger transport (step 1). The total passenger transport work (person km) in vehicles and trains is constant from 2004 to 2030. When implemented in the IDA Energy Plan, passenger transport is considered to be petrol-based road transport and the total train transport in 2004. In comparison with the reference, road passenger transport is reduced by 13 per cent in 2030. In train transport, the stabilisation at the 2004 level prevents the quantity of train passenger transport from falling as projected.

2.2.2 No measures on the development of goods transport (step 1). There is virtually no transport of goods by train in the reference, so train transport is considered to be passenger transport. Regarding the road and sea transport of goods, the rate of increase is retained assuming that all diesel-based vehicle and ship transport is related to goods. The socio-economic costs of retaining the needs for passenger transport at the 2004 level are regarded as neutral, but require the restructuring of taxes and levies. With revenue-neutral restructuring of taxes from taxation of vehicle purchasing to a kilometre levy the passenger transport in vehicles can be reduced by up to 15 per cent. With this measure, passenger transport is kept at a constant in 2030 at the level of 2004. [17]

2.2.3 Reduced air transport increase (step 1). The fuel consumption for international and domestic aviation rises by 50 per cent from 2004 to 2030 in the reference. This increase is limited to 30 per cent in this proposal. To achieve the reduced rate of increase in aviation, international policies are required. Fuels for air transport are levy-free because of international conventions as opposed to fuels for vehicles and trains. Putting levy on fuels for aviation as well is an example that could guarantee a fair competition between the different types of transport and limit the growth in air transport. Another example of an international measure is to implement levy on aviation for the socio-economic costs connected to global warming, i.e. on CO_2 emissions and emissions of other substances with a global warming effect. These substances are particles that condense water vapour, ozone and cirrus clouds. In the EU, aviation is expected to increase by 4 per cent annually in the period from 2008 to 2012 if no interventions are implemented. The European Commission has estimated that this increase can be halved [19]. However, it requires that air transport, like other energy consuming sectors, is integrated into the European CO_2 quota regulation.

The increase in the international air transport from Denmark has been 2 per cent annually since 1990. In the DEAs reference for 2030, the annual growth in the international air transport is expected to be 1,5 per cent. A more moderate increase in air transport implicates that the annual increase is reduced to 1 per cent. It is estimated that this can be achieved by implementing a separate trading scheme within aviation for CO_2 emissions and the other mentioned substances that have a global warming effect. For every unit of global warming effect of CO_2 that the plane emits, the other substances have between two and five time's units of global warming effects. The socio-economic costs of the limited rate of increase in aviation are estimated to be revenue-neutral.

2.2.4 Passenger transport to public transport and bicycles (step 2). The proposal of transferring 20 per cent of road transport to trains, ships and bicycle is calculated on the basis of an environment scenario in a report with future scenarios for transport in Denmark. In this scenario, the focal point is mobility and reductions in CO_2 emissions achieved by transferring road transport to public transport [20]. In total, 5 per cent of the passenger transport on roads is transferred to trains and 5 per cent is transferred to bicycles. The conditions for more bicycles are ideal because Denmark is rather flat. The primary rail track network is electrified and expanded. Also commuter trains, light Rail and metros are expanded. The changes in fuel consumption caused by the electrified primary rail track network are estimated on the basis of specifications of the rail transport from The National Rail Authority [17]. In the analyses here, passenger transport is five times more energy-efficient compared to average vehicles in 2030. Today, this relation is one to three because of the large quantity of diesel trains [17].

In total, 5 per cent of transport of goods is transferred to trains and 5 per cent to ships. The freight of goods via rail is ten times more energy-efficient compared to heavy vehicle and lorries already today [17]. This relation is used for transferring the freight of goods to rail transport. Sea transport of goods is also ten times more energy-efficient.

In the analyses, both the transport of passengers and of goods is transferred to electric trains. The increased amount of passengers and goods in trains and the electrified primary rail track network entails a reduction in the diesel consumption from 2,74 PJ to 1,21 PJ. The electricity consumption, on the other hand, is increased from 1,08 PJ to

2,02 PJ. Both the consumption of petrol and of diesel is reduced by 17,87 PJ. The use of diesel for shipping is increased by 0,89 PJ.

Table 1: Fuel consumption in the transport sector and implementation of the proposals in the IDA Energy Plan 2030.

Means of transport	**2004**	**%**	**Ref. 2030**	**%**	**Step 1**	**Step 2**	**Step 3**	**Step 4**
	PJ	**increase**	**PJ**	**reduction**	**PJ**	**PJ**	**PJ**	**PJ**
Road	**161,17**	*19*	**192,22**	*7*	**178,70**	**142,96**	**131,91**	**106,34**
- diesel	*72,25*	*24*	*89,78*	*0*	*89,78*	*71,91*	*71,91*	*59,13*
- petrol	*88,92*	*15*	*102,44*	*13*	*88,92*	*71,05*	*56,84*	*22,78*
- bioethanol	*0,00*		*0,00*		*0,00*			*21,27*
- electricity	*0,00*		*0,00*		*0,00*		*3,16*	*3,16*
Railroad	**3,82**	-6	**3,60**	*10*	**3,23**	**5,61**	**5,61**	**5,61**
- diesel	*2,74*	*0*	*2,73*	*56*	*1,21*	*1,21*	*1,21*	*1,21*
- electricity	*1,08*	-19	*0,87*	*-132*	*2,02*	*4,40*	*4,40*	*4,40*
Domestic, JP4	**1,36**	*48*	**2,02**	*12*	**1,77**	**1,77**	**1,77**	**1,77**
Internat., JP4	**30,84**	*48*	**45,68**	*12*	**40,09**	**40,09**	**40,09**	**40,09**
Shipping	**5,01**	*-3*	**4,84**	*0*	**4,84**	**5,73**	**5,73**	**5,73**
- fuel oil	*1,82*	*0*	*1,82*	*0*	*1,82*	*1,82*	*1,82*	*1,82*
- diesel	*3,19*	-5	*3,02*	*0*	*3,02*	*3,91*	*3,91*	*3,91*
Defence	**1,66**	*0*	**1,66**	*0*	**1,66**	**1,66**	**1,66**	**1,66**
Bicycle	**0,00**	-	**0,00**	-	**0,00**	**0,00**	**0,00**	**0,00**
Sum	**203,87**	-	**250,03**	*8*	**230,30**	**197,83**	**186,78**	**161,21**

With the suggested investments, the transfer of, in total, 20 per cent of all road transport can be achieved [17]. The required investments in more and better national and local rail track networks, commuter trains, light Rail, metros, upgrading of tracks for higher speed trains, better infrastructure for freight of goods etc. are estimated by the authors of [20] to be DKK 200 bn. (€ 27 bn.). Furthermore, DKK 3 bn. is required for investments in bicycle infrastructure and park and ride facilities for bicycles and vehicles. A detailed list of the investments in Danish rail track network is available in [17;20]. The investments will reduce the journey time between the regions in Denmark significantly.

The lifetime of the investments in public transport is estimated to be 100 years for the course of the tracks. This applies to 50 per cent of the investment. The rest is estimated to have a 30-year lifetime. With a socio-economic interest rate of 3 per cent, the annual depreciation is DKK 8,38 bn. (€ 1,12 bn.). In effect, the market share of both public transport and transport of goods via rail is doubled from the level today [17] which is equal to the transfer of 20 per cent of the road transport in the IDA Energy Plan 2030.

This transfer from vehicles to public transport and goods transport via rail entails less road congestion and less fuel consumption. A conservative estimate of the value of this congestion is used in the analyses here. Already in 2004, the socio-economic costs of congestion in the Copenhagen area alone was estimated to be DKK 5,7 bn. (€ 0,76 bn.). The difference in annual costs is thus DKK 2,69 bn. (€ 0,36 bn.) which is used in the analyses here as an investment of DKK 53 bn. with a lifetime of 30 years.

2.2.5 Transfer of road transport to battery electric vehicles (step 3). In addition to the proposals above, 20 per cent of the remaining passenger transport is transferred to battery electric vehicles (BEV). Today, the fuel efficiency of the BEV is 75 per cent and the internal combustion engine vehicle efficiency (ICE) is 18 per cent. In 2030, the BEV efficiency will be 90 per cent ab grid. If the development of ICE continues, the efficiency will be 20 per cent or 17,9 km/l petrol in 2030, which is an improvement of 15 per cent compared to today [17]. In the calculations, it is assumed that the number of passengers in vehicles are the same as today in 2030 and that only petrol ICE is replaced. If 20 per cent of the passenger transport is transferred, 3,16 PJ electricity is consumed to replace 20 per cent of 71,05 PJ, equal to 56,84 PJ. Please note that if the energy efficiency of an average vehicle is 20 per cent or 17,9 km/l in 2030, then the corresponding energy efficiency of BEV at 90 per cent is 80,7 km/l or 8,1 km/kWh.

The socio-economic costs of BEV are 80 per cent higher than those of ICE. This implies that the lithium battery is not replaced in the 15-year lifetime of the vehicle, but not that there will be a substantial development and streamlining in the production of BEV [17]. The socio-economic costs of an average vehicle are 80.000 DKK. A replacement of 20 per cent of the vehicle fleet will increase the annual socio-economic costs of cars by 16 per cent from the current DKK 13 bn. invested in vehicles annually in the reference. Extra annual costs of DKK 2 bn. (€ 0,27 bn.) are thus connected to a 20 per cent replacement with BEV. An extra investment of DKK 25,6 bn. (€ 3,41 bn.) is related to the replacement with BEV, which is estimated to have a lifetime of 15 years. The charging of vehicles is assumed to be flexible in the periods when the vehicles are parked. These periods are estimated by the use of driving patterns [14], assuming that only 70 per cent of the vehicles are grid-connected.

2.2.6 Better energy efficiency in the transport sector (step 4). The IDA Energy Plan 2030 proposal of a 30 per cent more efficient transport sector. This is related to the proposals of keeping the level of passenger transport at the 2004 level and introducing a lower rate of increase in air transport, i.e. after implementing step 1. It is achieved partly by transferring road transport to rail and replacing ICE with BEV, i.e. steps 2 and 3. The 231 PJ used in the transport sector have to be reduced to 162 PJ which implicates the improvement of the energy efficiency of road transport based on liquid fuels by 25 per cent to achieve the same passenger transport (person km). The fuel consumption of vehicles using liquid fuels has to be reduced to 106 PJ.

New vehicles in 2005 drove 15,6 km/l on average [21]. In 2030, vehicles will be 15 per cent more efficient without any additional international measures to improve the energy efficiency, i.e. 17,9 km/l. This is applied as an average in 2030 for ICE. An energy efficiency improvement of 30 per cent in passenger vehicles and heavy vehicles and lorries on liquid fuels could be achieved by transferring petrol vehicles to diesel vehicles, by promoting hybrid vehicles or potentially by promoting fuel cell vehicles. It could also be induced by gradually increasing the international demands for new vehicles. Here, half of the energy efficiency is covered by diesel vehicles and half by petrol vehicles.

This energy efficiency improvement is principally socio-economically revenue-neutral. Partly, because ordinary passenger vehicles with an efficiency of 23 km/l can already be purchased which is 30 per cent more efficient than the 17,9 km/l in the reference; partly, because the energy efficiency of heavy vehicles is already being improved. In the analyses here, 1 per cent of the passenger vehicles are replaced with hybrid vehicles and 1 per cent are replaced with fuel cell vehicles, in total 40.000 vehicles. The socio-economic investment costs of hybrid vehicles are app. 20 per cent higher and, for fuel cell vehicles, 100 per cent higher than average vehicles in 2030 [17].

Here, the calculations include an extra investment cost of 20 per cent of 20.000 vehicles in 2030, corresponding to app. DKK 320 mill. (€ 43 mill.). The 20.000 fuel cell vehicles are implemented with extra investment costs of DKK 1,6 bn. (€ 213 mill.). Both types of vehicles are assumed to have a lifetime of 15 years in 2030. In total, these amount to extra annual investment costs of DKK 160 mill. (€ 21 mill.), corresponding to 1 per cent of the total annual investment in vehicles in the reference.

The consumption of fuels is assumed improved to reach the goal of a total annual consumption of 106 PJ by the means mentioned above. The same shares of petrol and diesel are assumed from step 3 to step 4. The implementation of the improvements mentioned above requires that an average passenger vehicle drives 22,5 km/l in 2030.

2.2.7 Biofuels for road transport (step 4). The share of bioethanol is 20 per cent of the total fuel consumption of road transport in the IDA Energy Plan. This corresponds to 21,16 PJ bioethanol. Here, this is implemented with 30 per cent vehicles using at least 85 per cent bioethanol. Extra costs of 10 per cent are connected to these vehicles. 30 per cent of the vehicles mainly using bioethanol correspond to app. 470.000 vehicles, equivalent to DKK 3,74 bn. (€ 0,5 bn.). With a lifetime of 15 years, this is an annual investment of DKK 300 mill. (€ 40 mill.) at an interest rate of 3 per cent. This corresponds to app. 2 per cent of the total annual investment in vehicles in the reference. The remaining bioethanol is utilized in the rest of the vehicle fleet.

The biomass consumption and costs of producing bioethanol are estimated with a 2006 IBUS plant (Integrated Biomass Utilisation System) [17]. The energy input is 2.320 TJ of straw, 36 GWh electricity and 497 TJ of steam/heat. This can be converted into 1.064 TJ of bioethanol, 1.064 TJ of biomass and 38 tons of animal feed (mollases 70 per cent dry matter). The heating value of the animal feed can be estimated to be equal to 295 TJ of biomass, which, in the calculation here, is related to the utilised amount of biomass for the processes. The plant is placed in the proximity of an existing extraction power plant that uses biomass as supplementary fuel. The plant can produce the steam and heat required at a marginal efficiency of 167 per cent. The biomass needed in the process is calculated as the marginal fuel, equal to 931 TJ biomass subtracting the biomass needed to produce the extra steam/heat, equal to 298 TJ. The net biomass for the process is thus 1.259 TJ to produce 948 TJ of bioethanol, adding an electricity demand of 36 GWh.

The investment costs of this IBUS plant are DKK 590 mill. (€ 79 mill.) and operation and annual maintenance costs of app. DKK 30 mill. (€ 4 mill.). The lifetime of the plant is 20 years. In addition to these costs, the costs of enzymes have to be estimated. This is rather complicated as no enzymes are available on the market. Based on estimates from an enzyme producer, the costs are 0,95 DKK/liter (0,13 €/liter) in 2006. In 2030, the costs are estimated to be 0,16 DKK/liter. Using the lower heating value of 21 MJ/liter equal to DKK 43 mill. annually in 2006 or app. DKK 7 mill. (€ 0,9 mill.) in 2030.

The future plants in 2015-2030 will presumably not produce more bioethanol but plants will be more effective using less heat and electricity and thus involving less investment costs for the same production. It is estimated that 20 per cent less steam/heat and 30 per cent less electricity is required. Also a 15 per cent saving in operations and maintenance is estimated. On the other hand, it cannot be expected that the steam required will be produced at a marginal efficiency of 167 per cent as there will be less condensing power production. The marginal efficiency is thus reduced to 130 per cent, corresponding to condensing power production half the time and boiler production half the time. This is equal to 497 TJ reduced by 20 per cent to 398 TJ steam/heat requiring 305 TJ of fuel. For the production of 21,16 PJ of bioethanol in 2030, this results in 28,56 PJ net biomass required and 0,56 TWh of electricity. In total, the investment costs are DKK 11 bn. (€ 1,47 bn.) with a lifetime of 20 years and operation and maintenance costs of 6 per cent. In table 2, the results of the calculations above are listed.

Table 2: Production and costs of bioethanol using the IBUS concept.

	IBUS 2006	IBUS 2015-30
Straw	2320 TJ	2320 TJ
Biomass (incl. feed)	- 1359 TJ	- 1359 TJ
Fuels for steam/heat	+ 298 TJ	+ 305 TJ
Net biomass	1259 TJ	1266 TJ
Bioethanol	948 TJ	948 TJ
Biomass/ethanol factor	1,30	1,35
Investment costs	590 mill. DKK	500 mill. DKK
Operation and maintenance	30 mill. DKK/year	25 mill. DKK/year
Enzyme costs	43 mill. DKK/year	7 mill. DKK/year
Electricity consumption	36 GWh	25 GWh

2.3 Summary of transport and mobility proposals for 2030

In table 3, step 4 from table 1 is listed as input data on transport for the analyses conducted in the EnergyPLAN model. The proposals are divided into the types of fuels in the reference and in the IDA Energy Plan. In comparison to table 1, 35 per cent biomass for bioethanol production has been added, i.e. the description above.

Table 3: Fuel consumption of transport.

TWh/year	Reference 2030	IDA 2030
JP4 (for aviation)	13,25	11,63
Diesel	27,50	18,82
Petrol	28,46	6,33
Biomass for ethanol	-	7,98
Electricity	0,24	2,10
Sum	69,45	46,85

2.4 Inputs for a 100 renewable transport sector

In addition to the initiatives above, further proposals are needed to enable a conversion to a 100 per cent renewable energy system in 2050. Further savings are made and the electricity and heat production is converted into a combination of intermittent renewable energy, heat pumps and biomass processed for high temperature fuel cells. In [15] all proposal are listed. The following further proposals are put forward within transport:

- The total passenger and goods transport demand (person km and ton km) is kept constant at the 2030 level
- 50 per cent of goods transport is transferred to trains
- All remaining use of oil product within the transport sector is converted into electricity, hydrogen and biofuels.

In table 3 the fuel consumption in IDA 2030 is listed. In the proposal for 2050 50 per cent of the diesel consumption is transferred to trains. The total consumption of fossil fuels is thus reduced from 36,78 TWh to 28,57 TWh and the electricity consumption increases by 0,82 TWh. The remaining oil consumption is parted in three and is replaced by BEV, hydrogen fuel cell vehicles vehicles and biofuels. This corresponds to 9,52 TWh oil is replaced by 2,10 TWh electricity, 9,52 TWh hydrogen and 12,86 TWh biomass. In total the fuel consumption for transport is now 20,78 TWh biomass, 9,52 TWh hydrogen and 4,78 TWh electricity with the total electricity consumption for trains increased to 1,80 TWh annually and for BEV 2,98 TWh. The hydrogen is assumed produced in electrolysers with an efficiency of 85 per cent including losses in the storage.

3. RESULTS

The results are divided into technical opportunities and treats for the implementation of a sustainable development within transport and economic analysis of the proposals.

3.1 Fifty per cent renewable energy for transport in 2030

The stabilisation of the transport needs is absolutely crucial in a sustainable energy development. This proposal ensures that a large proportion that the dependency of fuels for transport is not increased and thus that the proportion of renewable energy for transport can be larger than otherwise. These initiatives require long-term planning of the urban development. The result is that the fuel for transport is 20 PJ lower and thus less oil or other fuels is needed. The efficiency improvements in the ICE vehicles is also important in this respects as it decreases the fuel dependency by 25 PJ.

The electricity consumption for transport is significantly larger than in the reference energy system. It is increased with 1,84 TWh. Annually the total electricity production from intermittent renewable energy is more than 55 per cent and app. 40 per cent of the electricity production in CHPs is bassed on biomass. Thus the energy system analysis has resulted in the transport technologies using electricity to a large extent are using renewals. The electricity used for trains uses the main part of the electricity in the day and uses on average less than the renewable energy electricity fractions mentioned above. The BEV are used for the integration of renewable energy. The charging is flexible and The BEV uses close to 100 per cent renewable energy.

The total biomass consumption in the 2030 system is 180 PJ (50 TWh). The DEA has assessed the potential Danish biomass resource assuming that it has to be residual resources to be 165 PJ in 2005. This resource can principally be increased substantially by altering the drops grown, also without a drop in the production of food. In total 417 PJ is considered possible [17]. The total consumption of biomass in the 2030 energy system is listed in fig. 2. Energy crops such as maize or beets can be grown without affecting agricultural output. This is possible partly because co-production of liquid biofuels, fuels and of fodder decreases the use of farmland elsewhere, partly because fallow farmland can be utilised.

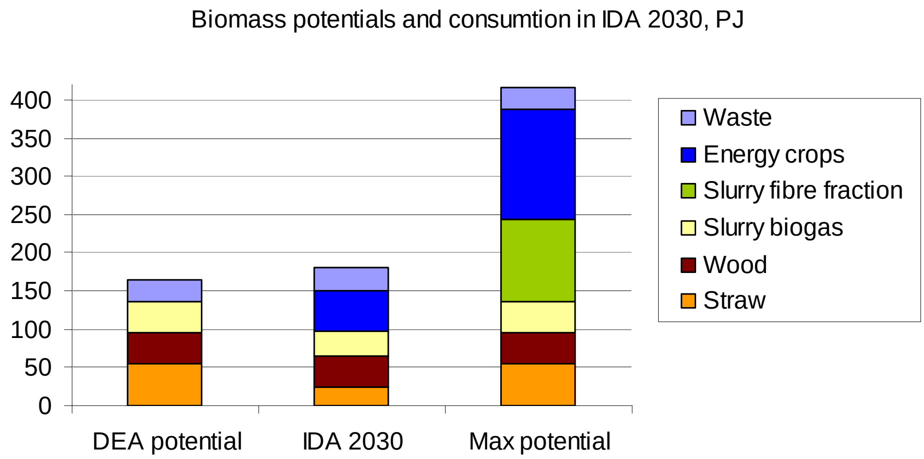

Fig. 2 Biomass potential and consumption in IDA 2030.

The gross biomass consumption for the production of bioethanol is 52 PJ. According to the DEA the potential for the use of straw is app. 25 PJ considering the agricultural production. Here 27 PJ of the biomass needed for bioethanol is thus produced with energy crops. In the IDA Energy Plan 5 per cent of the farmland is converted into energy crops. The 144 PJ requires an altered production in 15 percent of farmland, and up to 20 per cent is potentially possible without effecting the agricultural production [17]. The net consumption of biomass for bioethanol is 29 PJ. The remaining biomass in table 4 is for industry, electricity and heating. In the proposed energy system for 2030 it has been assured that the biomass resources are available for the transfer to a 50 per cent renewable energy system including 20 per cent biofuels in the transport sector.

Overall the results of the technical analyses of the energy system integrating the transport sector will enable that app. 50 per cent of the transport km to be covered by renewable energy in 2030. In total 20 per cent of fuels for transport is renewable energy.

3.2 100 per cent renewable energy for transport in 2050

The 2050 energy system is entirely based upon renewable energy. In the 2050 the transport sector plays an even more important part in the integration of intermittent renewable energy. Especially the use of electricity for transport is an important part of the energy system as it makes it possible to relocate electricity consumption and simultaneously replaces rather inefficient technologies.

The increase in the proportion of biofuels for transport in the 2050 system requires one or more of the following initiatives. A larger proportion of the potential straw resources has to be utilised, more energy crops has to be grown or technologies has to be developed in order to utilise the fibre fraction in slurry. The gross biomass demand for bioethanol production is 190 PJ. The increased demand of bioethanol is dependent upon the change from natural gas to biomasse at fuel cell CHPs.

Although within the transport sector this is technically possible, the exact design of the surrounding 100 per cent renewable energy system requires further research. This total conversion to renewals requires further analysis of the balance between wind and biomass [15]. The one requires rather large investments in wind and electrolyser capacity, the other requires rather large proportions of biomass.

3.3 Socio economic feasibility studies

The results of the socio-economic feasibility studies include an analysis of the total energy system as well as assessments of each individual proposal for the 50 percent renewable energy system for 2030. Demands and productions, fuel consumptions and CO_2 emissions are analysed for both the 2030 energy system and for the 100 percent renewable energy system proposal.

The overall results of the socio-economic feasibility studies show that the energy system proposed for 2030 in the IDA Energy Plan gives a net benefit of DKK 15 bn. annually (€ 2 bn.) in comparison with the reference energy system. When analysing the electricity exchange of the two systems, the results are that the systems are equally able to benefit from the exchange with app. DKK 500 mill. annually with varying fuel prices (€ 67 mill.). The sensitivity analysis includes doubling the investment costs and doubling the interest rate to 6 per cent. The result is that the costs of the to energy systems balances. The proposals have been analysed individually. Within transport the net benefit of the proposals is app. DKK 7. bn. (€ 0,9 bn.), see fig. 3.

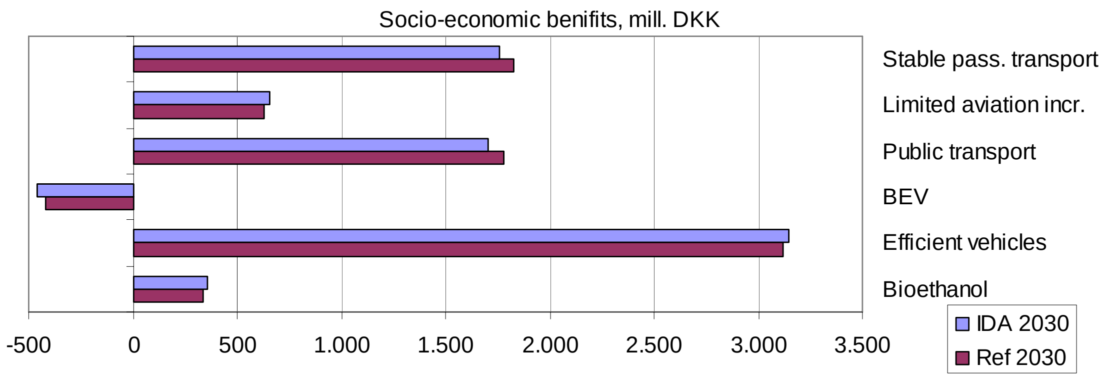

Fig. 3 The socio-economic benefits of the proposals in the 50 per cent renewable energy system and in the DEA reference for 2030.

The proposals have been analysed both in the 2030 system proposed in the IDA Energy Plan and in the reference for 2030. The conclusion is, that the proposals have a net socio-economic benefits in both systems. The condition for the benefits of the limited growth of road and air transport and the better efficiency in vehicles is that the costs are revenue-neutral. Even if this proposal is connected to some costs, the benefits for society are rather high as is will decrease the dependency of fuels. The benefits of public transport are connected to the fuel savings and the improved mobility in society. The benefits connected to mobility may be even higher than estimated in the analyses. BEVs are connected to socio-economic costs, but are necessary in the long term for transferring to a 100 per cent renewable energy system. BEVs improves the efficiency in transport and reduces the CO2 emissions as well as enable integration intermittent renewals. Bioethanol has a net benefit and is crucial as it decreases the oil dependency. The biomass recourse is limited though and has to be combined with other solutions.

3.4 Transport fuel supply and CO2 emissions

The fuel consumption for transport is reduced significantly. In total the electricity and fuel consumption for transport is reduced from 250 PJ to 161 PJ in 2030. In the 100 renewable energy system the total consumption is 126 PJ. This enables that the transport sector can be based on 100 per cent renewable energy. In fig. 4 the reductions in CO_2 emissions of each proposal is illustrated for 2030. The total CO_2 emission reduction is app. 8 mill. ton corresponding to app. half of the reference CO2 emissions connected to transport.

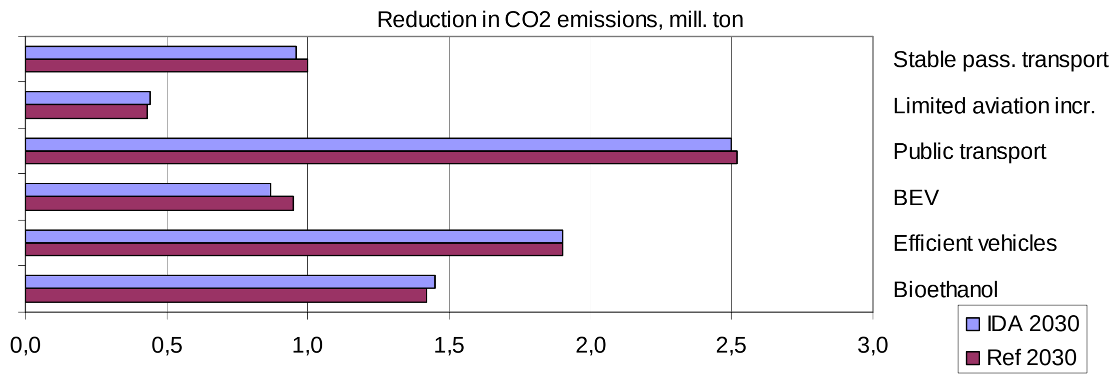

Fig. 4 The reductions in CO_2 emissions of the proposals in the 50 per cent renewable energy system and in the DEA reference for 2030.

4. Conclusion

The conversion of the transport sector to 100 per cent renewable energy is possible, but is connecting to an extremely challenging process before reaching such a goal. Locating solutions that integrates transport and energy systems is crucial, as it enables utilising more intermittent renewable energy in both the transport and the electricity and heating sectors. It also enables a more efficient utilisation of the biomass resources without putting strain on the biomass resource. It is only possible to propose a coherent sustainable development within transport if transport is analysed in the context of the surrounding energy system and resource potentials.

The increasing international focus on the transport sector is mainly centred upon biofuels. Biomass is however a limited resource that cannot induce a sustainable path for transport on its own. If utilised without control biofuels will effect the food production. In this proposal biofuels play an important part in combination with other equally important proposals.

A 100 per cent renewable energy transport development for Denmark is possible without affecting the production of food. It is however connected to large challenges in the process towards this goal, requiring multiple measures and integrating transport with the remaining energy system. These challenges can only be meet by combining planning for this long term goal, in the shorter term solutions. The 50 per cent energy system for 2030 is a shorter term proposal that enables the transport sector to reach the long term goal. The short term 2030 energy system than does enables the later process towards 100 per cent renewable energy has substantial socio-economic benefits.

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