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100% Renewable energy systems, climate mitigation and economic growth

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ABSTRACT

Greenhouse gas mitigation strategies are generally considered costly with world leaders often engaging in debate concerning the costs of mitigation and the distribution of these costs between different countries. In this paper, the analyses and results of the design of a 100% renewable energy system by the year 2050 are presented for a complete energy system including transport. Two short-term transition target years in the process towards this goal are analysed for 2015 and 2030. The energy systems are analysed and designed with hour-by-hour energy system analyses. The analyses reveal that implementing energy savings, renewable energy and more efficient conversion technologies can have positive socio-economic effects, create employment and potentially lead to large earnings on exports. If externalities such as health effects are included, even more benefits can be expected. 100% Renewable energy systems will be technically possible in the future, and may even be economically beneficial compared to the business-as-usual energy system. Hence, the current debate between leaders should reflect a combination of these two main challenges.

1. Introduction

If temperature increases are to be held between 2 and 2.4 °C, the concentration of CO_2 equivalents in the atmosphere should be kept below between 445 and 490 ppm, according to the most recent report from the United Nations Intergovernmental Panel on Climate Change from 2007, IPCC Fourth Assessment Report: Climate Change 2007 (AR4) [1]. As the concentration of greenhouse gases has already reached about 450 ppm CO_2 equivalents in 2005, the IPCC has estimated that the discharge of greenhouse gases must peak as soon as possible, no later than the year 2015. Furthermore, the discharge of greenhouse gases must be reduced by 50–85% by 2050 compared with the year 2000. These reductions should lie closer to 85% than 50% to ensure a maximum of 2 °C increase. It is estimated that discharges per person must be reduced to between 0.8 and 2.5 tonnes of CO_2 equivalents per person per year.

Even with a 2 °C increase, significant changes in the climates of individual regions and the world at large are inevitable. However, it can be ensured that climate change does not accelerate beyond the point where the effects become self-reinforcing. In August 2009, the concentration of CO_2 in the atmosphere was 387 ppm [2]. The 2 °C increase estimate was based on a reduction to 350–400 ppm CO_2 in the atmosphere. However, the latest IPCC report from 2007 is based on data from 2005, and the latest results found by James Hansen from NASA, among others, indicate that this level is no longer sufficient. The most recent observations and model calculations show that a reduction to 350 ppm CO_2 in the atmosphere may be necessary, or even that anthropologically emitted climate gases must be avoided entirely in order to avoid irreparable damage [3–5]. In August 2009, the Chairman of the IPCC, recognised this point and stated that he now supports a 350 ppm CO_2 maximum instead of the 450 ppm in AR4 from 2007.

In the USA, the European Union and China, among others, policies have been formulated with the objective of decreasing emissions. And in many nations around the world, policies to raise the share of renewable energy are being initiated as part of the global response to climate change. The major debate occurring in many countries is mostly concerned with the costs of mitigating greenhouse gases.

Often, the debate about measures to mitigate greenhouse gases between world leaders is intertwined with other issues. These issues reflect the current geopolitical situation, the current interdependency between countries in the demand and supply of energy products, or issues regarding the negotiations between developed and developing countries in e.g. the World Trade Organisation (WTO). While costs have always been a central issue in the climate debate, as well as concerns regarding human equality. Recently, since the Poznan COP14 conference and the Copenhagen Accord from the COP15, the debate on costs and on transactions between developed and undeveloped countries has also reflected the international financial crisis. Developing countries have used the situation to emphasise the need for further aid and support. Also some

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developed countries, small and large, as well as members of the G8 and G20, have expressed the need to have lower goals than initially discussed because of tight national budgets in the midst of the financial crisis.

An active energy policy has already led to remarkable results in the decrease of emissions in Denmark which illustrates that a lot can be done with existing technologies while maintaining economic growth [6]. Over a period of 35 years, Denmark has managed to stabilise its primary energy supply through energy savings, and very high penetrations of wind power and combined heat and power (CHP). The primary energy demand is the same today as it was before the first oil crisis in the early 70s; however, CO_2-emissions are still high. In his opening speech to the Danish Parliament in October 2006, the Prime Minister announced the long-term target for Denmark: 100% independence from fossil fuels and nuclear power when Danish domestic oil and gas resources run out. A few months later, the Danish Association of Engineers put forward a proposal on how and when to achieve such targets [7–10], hence the active policy has the potential to continue after several years of inaction.

While some world leaders emphasise that the financial crisis is a showstopper regarding the mitigation of greenhouse gases, others contend that this is a golden opportunity to make these changes and create new jobs, which are not based on the notion of abundant fossil fuels. The Danish case shows that a lot can be done with existing technology while ensuring economic growth and developing new industries [6]. The question then becomes, what consequences might arise as a result of following a path towards a 100% renewable energy system?

In analysing such energy systems, often only single technology groups are analysed, such as the technologies for wind integration: CHP plants, battery electric vehicles, fuel cell vehicles, electrolysers, heat pumps, district heating and thermal storages [11–17]. Other studies often analyse island energy systems [18–23], or analyse the technical aspects of changes in total national energy systems while lacking e.g. the economic side [24,25].

In analysing 100% renewable energy systems, energy savings, efficient conversion technologies and the replacement of fossil fuels with renewable energy are essential elements to consider [26–29]. Others point out such systems as the importance of focusing on the four pillars in future energy systems as a way to a third industrial revolution [30,31]. The design of 100% renewable energy systems has to meet two major challenges. One challenge is to integrate a high share of intermittent resources into the energy system, especially concerning electricity supply [15,32–34]. The other is to include the transportation sector in the proposed strategies [10,35].

In this paper, the possibilities to reduce the emission of greenhouse gases by 90% is analysed by using only renewable energy sources; related socio-economic feasibility studies are concurrently presented. The analyses include: transport, the agricultural and industrial parts of greenhouse gas emissions, the potential for increased exports as well as domestic job creation, and the total effects on health costs. Electricity market trade analyses and sensitivity analyses are also included. The paper thus presents technical energy system analyses of the total system with a multitude of interrelated technologies as opposed to just one technology or one category of effects. The final year of analysis is 2050, while two intermediate years are also analysed, 2015 and 2030. The methodology includes hour-by-hour simulations leading to the design of flexible energy systems with the ability to balance electricity supply and demand and to exchange electricity production on the international electricity market. The paper describes the process, analyses and results of the IDA Climate Plan 2050 [36] from the Danish Society of Engineers (IDA) which was completed in August 2009. As a point of departure, the latest business-as-usual projection to 2030 from the Danish Energy Authority (DEA) has been used [37]. Utilizing the same methodology, a business-as-usual projection has been extended towards 2050 in the IDA Climate Plan 2050. The analyses presented here builds on the experience and analyses in previous analyses of 100% renewable energy systems [7–10]. However the technical and economic analyses are more comprehensive and include a short-term target year, a business-as-usual projection to 2050, as well as the first estimates of the socio-economic costs of a 100% renewable energy system for Denmark. Job effects and effects on health costs are also analysed.

2. Methodology

The methodology for analysing technologies in the renewable energy systems, and for assessing the technical and socio-economic consequences, can be divided into three parts. The data and technology input phase, the phase for adjusting energy systems technically and insuring flexibility, and finally the main technological and socio-economic results. In addition, fuel prices and CO_2-qouta prices are essential to the analyses [36].

There are four overall goals in the project:

- To reduce the emission of greenhouse gases by 90% in 2050.
- To maintain Denmark's self-sufficiency with energy.
- To enlarge Denmark's position with regard to trade in the climate and energy sectors.
- To expand the economy and prosperity of Denmark.

The target of maintaining security of supply refers to the fact that Denmark, at present, is a net exporter of energy due to the production of oil and natural gas in the North Sea. However, the reserves are expected to last for only a few more decades. Consequently, Denmark will soon either have to start importing energy or develop domestic renewable energy alternatives. The targets of expanding the economy are related to past experiences with stabilising primary energy consumption and creating new industries.

2.1. The creative innovation process

The Danish Association of Engineers appointed 2006 as the "Energy year", in which the organisation intended to make specific proposals to advocate an active energy policy in Denmark. The output here was the IDA Energy Plan 2030 [7–10]. In 2008, the process of updating and expanding the analyses was initiated as a part of the international project "Future Climate", in which 13 engineering associations from Sweden, Norway, Germany, India, United Kingdom, Finland, USA, Japan, Australia, Ireland, Bulgaria and Denmark participated. The combined recommendations were presented in September 2009, and both the Danish and the other national documents and analyses were based on a common set of parameters.

In the process of developing the scenarios in the IDA Climate Plan 2050 for Denmark, the methodology applied to the design of a future renewable energy system included the combination of a creative phase involving the inputs from experts, a detailed analytical phase involving the technical and economic analyses of the overall system, and feed-back regarding each individual proposal. In a forward and back process, each proposal was formed in such a way that it combined the best of the detailed expert knowledge with the ability of the proposal to fit cohesively into the overall system in terms of technical innovation, efficient energy supply and socio-economic feasibility. In addition, some of the proposals build on knowledge about the different technological components relating to the integration of intermittent renewable resources. Examples include: electric vehicles and fuel cell vehicles, district