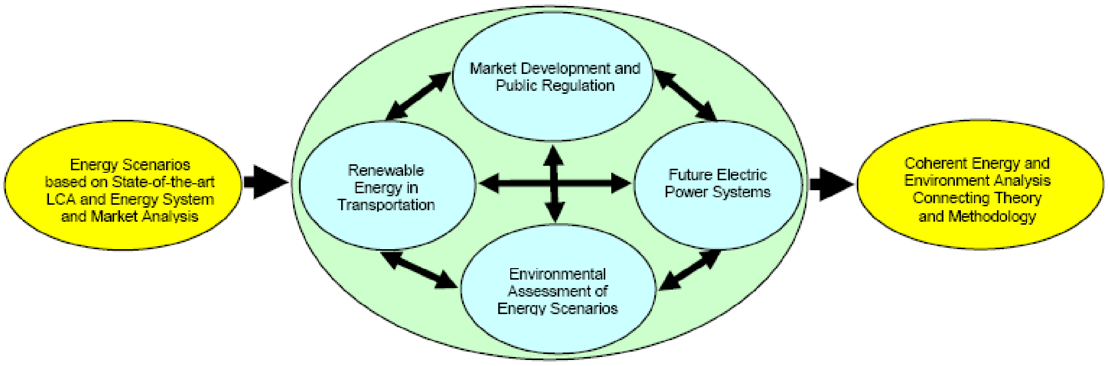
CEESA

Coherent Energy and Environmental System Analysis

WP1

From State-of-art-scenarios to Coherent Energy and Environmental Analyses.



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Introduction

This paper presents a draft proposal for the scenario framework for the CEESA project to be presented and discussed at the 2nd consortium meeting, 28-29 August 2007 at Gl. Vrå Slot.

The paper forms the input from work packages 1 and it consists of three parts:

1. Description of three scenarios on how to achieve a 100% renewable energy system in the future: 1) A biomass dominated scenario with low demand, 2) A wind dominated scenario with low demand and 3) A combined biomass and wind scenario with high demand. These three scenarios give the framework for the further work to be carried out in the different work packages of the CEESA-project.

2. A comparative Life Cycle Assessment (LCA) on screening level of the abovementioned two low energy demand scenarios based on 100 % renewable energy sources. No screening is yet performed for the combined biomass and wind scenario with high energy demand.

3. A short description of how demand is modelled by the use of macroeconomic modelling tools.

As mentioned the paper is a draft proposal and what is important seen from the viewpoint of WP1 is to get feed-back from the advisory panel and from other WPs in the CEESA-project to reach an appropriate scenario framework for future work.

100% Renewable Energy Scenario Framework for the CEESA project

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Introduction

This paper presents a draft proposal for the scenario framework for the future work within the CEESA project.

According to the project description *"the project will be initiated by defining sustainable energy scenarios which will be relevant in 20-30 years from now and are based on the existing state-of-the-art tools and methodologies of energy market and system analysis and environmental assessment."* Such scenarios provide a framework for the four sub-themes defined be the other WPs of the CEESA project.

The content of the scenario framework was defined in the project description as follows: *"During the first six-month period, task 1.1 will provide a common framework for the project by defining sustainable energy scenarios which will be relevant in 20-30 years from now. The scenarios will be related to a reference scenario which will be identified by the use of methodologies and models developed by Risø. These tools have, in many cases, been used in the energy planning processes of the Danish Government. The reference scenario will define the energy demand and the relation to economic development. By use of the energy system analysis model EnergyPLAN, developed at Aalborg University, a number of different 100% renewable energy scenarios will be defined, ……. The final definition of scenarios will be subject to a discussion between all project participants including an international advisory board."*

Discussions at the first consortium meeting and in the WP1 group

The design of a suitable scenario framework was discussed at the first CEESA project meeting in January 2007, in which the issue of high versus low energy demands were emphasised.

Based on these discussions it was afterwards decided by the WP1 group

- to base the framework on the 100% renewable energy scenarios from the "IDA Energy Plan" published by the Danish Association of Engineers in December 2006, which ensure scenarios with high degrees of biomass versus high degrees of wind, and
- to choose the high versus low energy demand parameter instead of the centralised versus distributed system. Consequently it has been decided to expand the two IDA scenarios with similar scenarios with higher energy demands. The energy demands anno 2004 has been chosen.

First it was intended to calculate two additional high demand scenarios, one based primarily on wind and the other on biomass. However in order to limit the number of alternative scenarios it was decided to calculate only one high demand alternative. Such alternative ended up needing more or less both the upper wind and the upper biomass resources of each of the two low demand scenarios.

Consequently the following three alternatives are suggested as a starting point for the CEESA project:
- ***Biomass scenario***. Based on the IDA 100% RES low demand, mostly biomass.
- ***Wind scenario.*** Based on the IDA 100% RES low demand, mostly wind
- ***High demand.*** Based on the 2004 energy demand, both wind and biomass.

Energy System Analysis at the EnergyPLAN computer model

The three 100% renewable energy systems have been analysed by use of the computer model EnergyPLAN. The model is an hour by hour simulation model with an emphasis on balancing electricity and heat supply and demands. The modelling comprises complete energy systems including the transportation sector.

Inputs include energy demands and renewable resources. For relevant demands such as electricity and district heating and relevant sources such as wind power and solar thermal, the inputs are distributed into hour by hour values using actual distribution from historical demands and productions.

The present version 7.0 of the EnergyPLAN model including input data for the analysis of the IDA Energy Plan and documentation of the model can be downloaded freely from the following home page: www.EnergyPLAN.eu.

The two IDA 100% RES scenarios are described in the attached paper “Energy System Analysis of 100 Per cent Renewable Energy Systems” (Lund and Mathiesen, 2007).

The high demand scenario has been calculated simply by increasing the following demands to the level of year 2004 (see overview in table 1):
- the electricity demand of 29.45 TWh/year is increased to 35.54 TWh/year.
- district heating demand (including grid losses) is increased from 25.96 to 38.48 TWh/year and the hour-distribution is adjusted accordingly. (In the high demand scenarios the duration curve equals the present shape, while in the low demand scenarios the shape is decided by savings done solely in the space heating demand (not grid loss and hot water))
- Individual heating is increased from 6.43 to 18.19 TWh/year (measured in net-heating demand and not fuel demand). The huge difference is caused partly by insulation (and the hour distribution is altered accordingly) and partly by including more houses in the district heating system in the low demand scenario.
- Fuel demand for industry is increased from 26.23 to 41.28 TWh/year.
- The transportation sector is the same, since the low demand scenario is based on the principle of stabilising the transportation work at the 2004 level. However the fuel consumption is different since the IDA scenarios involve a long list of placing oil by electricity, hydrogen and biofuels together with shifting form air and car transportation to ships and trains.
- In both scenarios the present anno 2004 fuel consumption for production and refining of oil and gas are excluded in the demands.

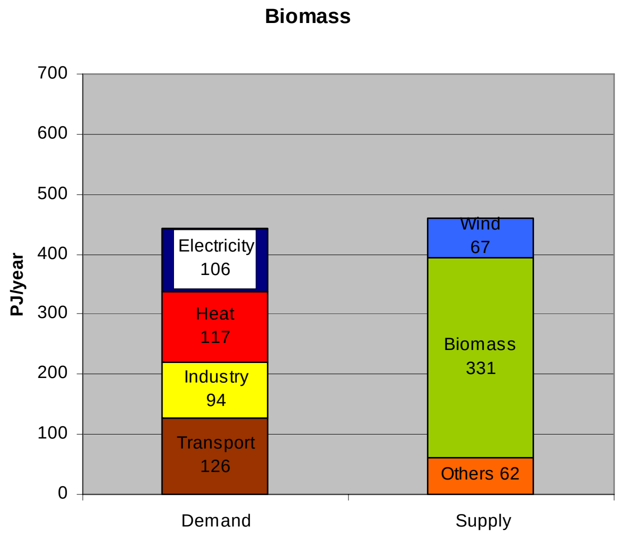
In all other aspect all three scenarios are the same.

The main inputs and results are shown in table 1 and the results are illustrated in the diagrams in figure 1.

Table 1: Inputs and results of the energy system analysis of three scenarios.	Biomass (Low demand)	Wind (Low demand)	High demand (Biomass and Wind)
Electricity demand (TWh/year)	29.45		35.54
District heating demand (TWh/year)	25.96		38.48 *)
Individual net heating (TWh(year)	6,43		18.19 **)
Industry (TWh/year)	26,23		41.28
Transport (incl. air and ship) (TWh/year)	35,08		35.08 ***)
North sea (Oil&gas production) + raff	0.00		0.00
Total (demands) (TWh/year)	123.15		168.57
Large FC CHP plants	64% el / 26% heat		
Small FC CHP plants	54% el / 36% heat		
Solar thermal	5,26		
Wave power	3,00		
Photo Voltaic	1,50		
Results (Primary Energy Supply)			
Solar thermal, Wave and PV	9.72	9.72	9.76
Heat Pumps (external heat source)	7.51	8.49	11.96
Wind Power (TWh/year)	18.71	53.79	53.79
Biomass (TWh/year)	91.92	55.75	102.10
Total (TWh/year)	127.86	127.75	177.61
Wind capacity (MW)	6,000	15,000	15,000
Electrolysers (MW-e)	6,000	16,000	18,500
Hydrogen storage (GWh)	200	3200	3200
CO2-emission (Mt/year)	0	0	0

*) Divided into 2.22 + 14.03 + 22.23 = 38.48
**) Net heating demand (Fuel demand is 22.35 TWh/year)
***) Transportation is the same, however the fuel demand in 2004 was higher (56.33 TWh) due to less electricity and less trains and ships etc.

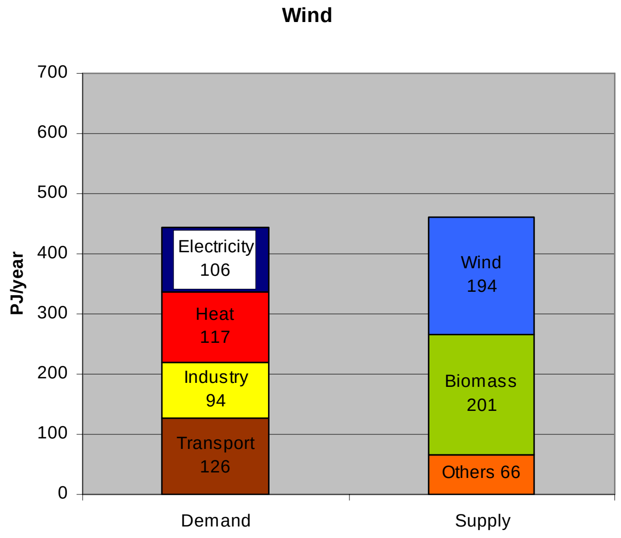
	JP	Petrol	fuel/diesel	Ngas	Coal	Biomass
Indv. Heating			8.51	8.48	0.01	5.35
Industry			17.78	16.34	2.47	4.69
Transport (relative to 2030 numbers)	10,79	23.16	22.39			
North Sea + raff.			8.17	8.71		



The Biomass Scenario

(Based on the IDA 100% RES 2050 proposal)

- Savings: 30-50% in space heating, electricity and industry compared to BAU 2030
- transportation demands stabilised at 2004 levels
- Efficiencies: More CHP and better power plants based on FC technology and heat pumps.
- 700 MW PV and 500 MW wave power. Solar thermal 15% of heat demand
- 6000 MW wind power

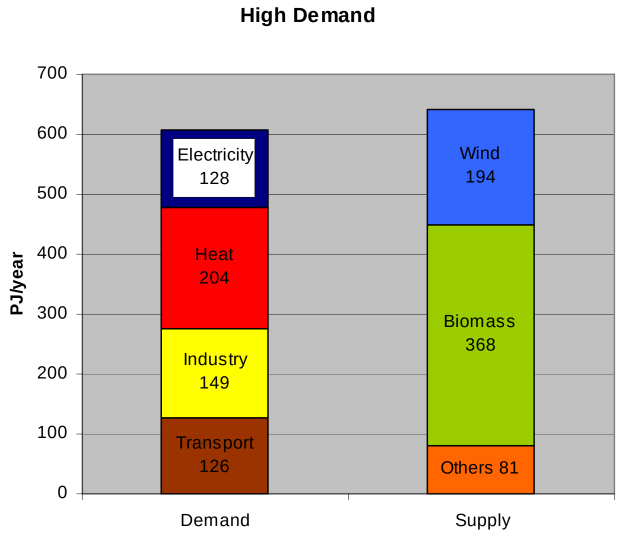


The Wind Scenario

(Based on the IDA 100% RES 2050 proposal)

Same as Biomass Scenario apart from

- 15,000 MW wind power instead of 6,000 MW
- additional 10,000 MW electrolysers and 3000 GWh hydrogen storages.



The High Demand Scenario

Same as Wind Scenario apart from

- 2004 electricity, heating, industry and transportation demands.
- 2,500 additional electrolysers to produce hydrogen for FC micro CHP units for individual heating.

Figure 1: Demand and supply in the three scenarios.

How to understand the scenarios

The scenarios are to be used as a first framework for the CEESA project. The scenarios are to be further developed in an on-going process during the period of the project, which among others will include the following work:

- The individual energy systems of each scenario will be better optimised, e.g. the capacities of electrolysers and choice of individual heating etc. This will take place within the WP1.
- LCA analyses of the scenarios will be incorporated. How to do this will call for further developments of theories and methodologies and is a core issue of the CEESA project. Such development will be based on a close collaboration between WP1 and WP4 and further involve the whole consortium.
- The analysis of scenarios will be expanded to include electricity (and eventual biomass fuel) exchange analyses. How to define and model external markets will be discussed between WP1 and WP5.
- The transportation alternatives will be further developed in WP2.
- How to design the best production of biomass resources will be developed in WP2.
- How to develop the electric grid will be discussed between WP1 and WP3. Such discussion may lead to additional scenarios including the distributed versus centralised parameter, which has so far not been included into the scenario framework.

LCA screening of 100 % Renewable Energy Source scenarios

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Introduction

This paper presents a comparative Life Cycle Assessment (LCA) on screening level of the two Danish low energy use scenarios based on 100 % Renewable Energy Sources (RES): one scenario which is mostly biomass focused and one scenario which is more wind power focused.

The screening gives an indication of differences in the environmental implications of the two scenarios. The overall goal of the screening is to create a foundation for the further LCA analyzes within the CEESA project. More specifically, the screening will support to:

- Reveal important impact categories, processes and parameters
- Identify methodological issues or uncertainties which must be investigated further

Method

The LCA is based on the EDIP methodology (EDIP: Environmental Declaration of Industrial Products) which is in agreement with the standards of the International Organisation for Standardisation, ISO. The modelling has been facilitated in GaBi4 LCA software. Environmental impacts and consumption of non renewable resources is included, while impacts on working environment have been excluded.

The environmental impacts represent impact potentials and not actual impacts in the environment. The impact potentials are expressed relative to a reference impact per person, i.e. they are normalized and expressed in Person Equivalents (PE). This allows for comparing the magnitude of different impact potentials. Resource consumptions are not only normalized but also weighted according to the global reserve available of the given resource. This makes it possible to quantify the seriousness of different resources consumptions considering resource scarcity. Thus, the resource consumptions are given in Person Reserves (PR).

The screening is based on output data from modelling of the two scenarios in EnergyPLAN and results are given per year. Due to the comparative approach applied, the LCA covers only aspects in which the two scenarios differ from each other. In terms of primary energy supply, the scenarios only differ in their utilization of biomass and wind power, while the use of other RES, solar thermal, wave power and photo voltaic is identical. Regarding biomass utilization, only the amount of biomass used for power and district heat production is different the scenarios in between. It is roughly assumed that the biomass feedstock used for this production is energy crops, thus assuming that biomass residues/waste are utilized for other applications of the energy system (transport, industrial heat production, etc.). As energy crop well suited for heat and power production and biomass gasification, the woody energy crop, willow, is assumed used. In the table on next page, an overview is given of the scenario differences and the specific technologies assumed when modelling these differences in the LCA.

Parameter	Unit	Biomass scenario	Wind scenario	Technology assumed	Scenario difference
Biomass for CHP/PP	TWh/y	42.79	6.86	SOFC plants using producer gas from two-staged biomass gasification	Operation Biomass gasification capacity
Biomass used in boilers	TWh/y	2.76	2.52	Boiler based on wood chips (grate firing)	Operation
Offshore wind power capacity	TWh/y	3000	12000	Offshore wind turbines	Capacity
Offshore wind power production	TWh/y	11.69	46.77		Operation
Electrolysis capacity (for grid 2 and 3)*	MW-e	0	10000	Plants using reversed SOFC's	Capacity
Electrolysis operation (for grid 2 and 3)*	TWh/y	0	14.43		Operation
Hydrogen for CHP	TWh/y	0	8.79	SOFC plants using hydrogen	Operation
Hydrogen used in boilers	TWh/y	0	3.52	Boilers using hydrogen	Operation
Hydrogen storage (for grid 2 and 3)*	TWh/y	0	3.00	High pressurized tanks (glass fibre laminated steel tanks, 30 bar)	Capacity

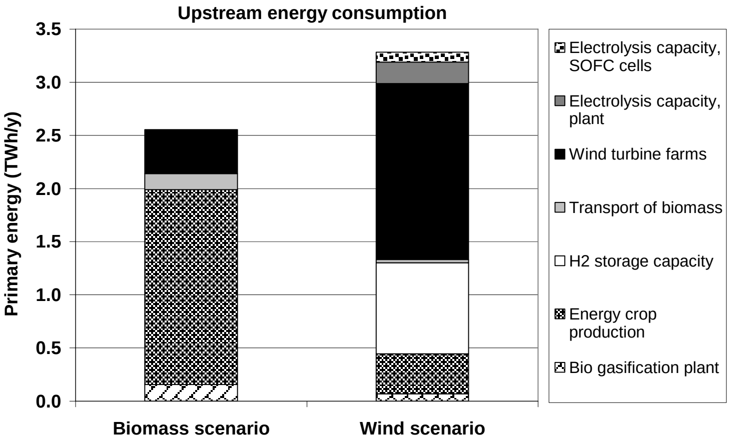
* Grid 2 and 3 is meant to represent district heating systems based on small and large CHP plants, respectively. CHP: Combined Heat and Power, PP: Power Production, SOFC: Solid Oxide Fuel Cell (planar cells assumed).

A large share of the materials/inputs used in the scenarios is likely to be produced in countries outside Denmark. As such, the production of these inputs cannot immediately be assumed to be based on renewable energy sources. In a life cycle perspective, upstream energy consumption (power, process heat and transport) traditionally contributes to a significant part of the environmental impacts of products/product systems. The impacts associated with energy consumption is highly dependant on the given energy production technology. However, it is highly uncertain which technologies will deliver the marginal power production, and heat production for the processes involved in the scenarios. The uncertainty is particularly high considering the time horizon for the 100 % RES scenarios, which might be as long as e.g. 2050. Based on the above considerations, upstream energy use is modelled separately. Thus, the results concerning environmental impacts and resource consumptions do not cover energy production processes. Instead, the energy consumption is quantified in energy units serving as an indicator for impacts and resource consumptions associated with energy use. This approach results in a transparent model which at the same time is flexible in the sense that sensitivity scenarios can later be set up depending on which energy production technologies are assumed.

Recycling is assumed for materials which are typically recycled, such as steel, iron, aluminium, lead and copper. However, material losses will still exist resulting in net waste generation. Apart from quantifying net waste generation in amounts, emissions from the given waste deposits are for the main part also included.

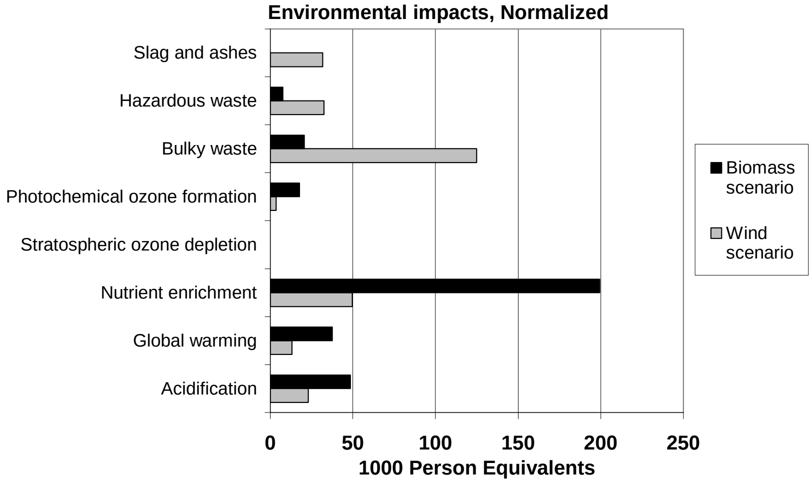
Results

According to the screening, more energy is used upstream in the Wind scenario compared to the Biomass scenario.



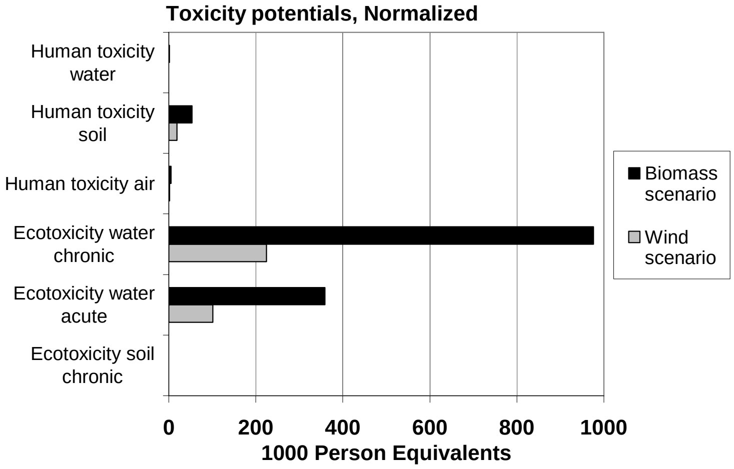
The main part of the energy use in the Wind scenario stems from manufacturing of offshore wind turbine farms and hydrogen storage tanks, while in the Biomass scenario, energy crop production is the dominating energy consumer.

In both scenarios, the main share of the primary energy consumption takes place in material production and not in manufacturing of components/plants or in disposal processes.



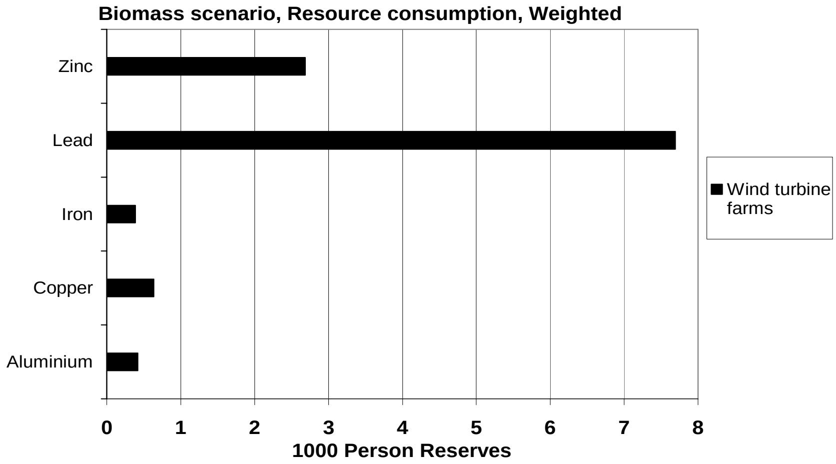
As illustrated, the Wind scenario is characterized by larger waste generation, i.e. amount of bulky waste, hazardous waste, and slag and ashes. The higher amounts of waste are mainly generated in the disposal of wind turbine farms, hydrogen storage tanks and electrolysis plants.

On the other hand, the Biomass scenario induces a higher magnitude of nutrient enrichment, global warming, acidification and photochemical ozone formation compared to the Wind scenario. Larger energy crop production, and production of fertilizers for this purpose in the Biomass, is the explanation for the larger contribution to the first three of these impact categories. The main emissions contributing to these impacts are nitrate and phosphate leaching, nitrous oxide, ammonia, and nitrogen oxide emissions to air. Hydrocarbon emissions from SOFC plants based on biomass producer gas cause the higher contribution to photochemical ozone formation in the Biomass scenario.

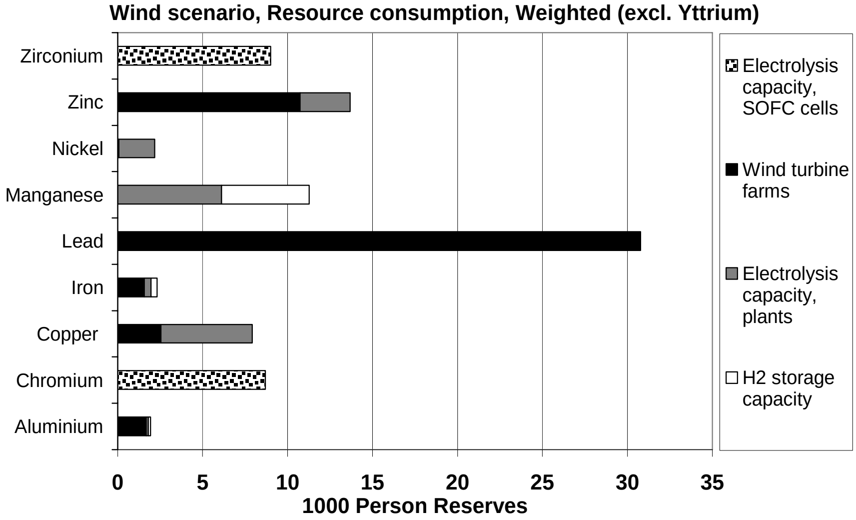


In terms of toxicity potentials, the Biomass scenario has significantly higher ecotoxicity contribution to the water environment. The reason is the higher use of pesticides due to the larger energy crop production.

In the Biomass scenario, the main consumption of scarce resources is associated with the material use for manufacturing of offshore wind turbines. As illustrated on the figure on next page, this comprises consumption of zinc, lead, iron, copper and aluminium. However, considering resource scarcity, the resource consumption in the Wind scenario is considerably more critical. As such, the total resource consumption in the Wind scenario is approximately $1220 \cdot 10^3$ PR compared to $12 \cdot 10^3$ PR in the Biomass scenario. The consumption of yttrium for the ceramic materials of the reversed SOFC's in the Wind scenario is the dominating resource consumption ($1140 \cdot 10^3$ PR).



An yttrium consumption of more than one million PR per year is indeed critical. As such, from a global sustainability perspective, in five years Denmark would have used the yttrium reserve available for Danish inhabitants and all future Danish generations.



Apart from the yttrium consumption, the Wind scenario involves consumption of zirconium and chrome for the SOFC unit cells as well as other scarce resources for the manufacturing of offshore wind turbines, electrolysis plants and hydrogen storage tanks.

According to the screening, the following processes are central for the comparative LCA: energy crop production and manufacturing and disposal of offshore wind turbine farms, hydrogen storage systems, electrolysis plants including reversed SOFC's. In the further LCA, particular attention should therefore be paid to these areas.

Problems/uncertainties for further investigation

Some of the most important methodological problems/uncertainties identified are listed below:

- Type/s of probable marginal technologies providing power, heat and transport for processes taking place outside Denmark
- Possible feedback of upstream energy consumption to EnergyPLAN-scenarios (e.g. adding upstream power consumption to the electricity demand in EnergyPLAN)
- Type of future system/s for storage and distribution of hydrogen
- Size of future offshore wind turbines (MW capacity per wind turbine)
- Use of energy crops relative to use of biomass residues/waste
- Expected degree of recycling of the various materials

- System expansions crediting for differences in e.g. use of agricultural land for energy crops
- Inclusion of other relevant impacts, e.g. impacts on landscape and biodiversity

These issues should be investigated in the further research within the CEESA project.

Reference scenario and macro-economic effects of alternative scenarios

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Internal document, draft, July 11, 2007

A reference scenario and macro-economic effects of the alternative scenarios are analysed using the ADAM/EMMA model. ADAM is a macro-econometric model used for official forecasts of the economic development in Denmark, and EMMA is a model describing related energy demands. At present, the model distinguishes 20 branches, household consumption for heating, transport, and electricity for other uses than heating, and for each branch and category of private consumption 7 types of energy. EMMA may be run as an after-model to ADAM or as an integrated model where energy-demand and conversion determined in EMMA is fed back into ADAM determining an alternative macro-economic development.
As an after-model inputs to EMMA are production and consumption generated by ADAM, energy prices, and forecasts of efficiency improvements in each branch and category of private consumption.

Generating a reference scenario, the point of departure will be using EMMA as an after-model, assuming a baseline economic development forecasted by the Ministry of Finance, energy prices projected by the Danish Energy Authority (ENS), and a continuation of past energy efficiency improvements. Next, to get consistency between the economic and energy development, ADAM/EMMA is run integrated, giving a slightly different economic development and energy consumption. For the further analyses, consistency between the economic and energy-demand developments are more important than whether the assumed economic development is an official forecast or just close to an official forecast.
As a first exercise the economic forecast will be taken from "konvergensprogrammet dec. 2006", energy prices from ENS (2006) and efficiency improvements as a continuation of improvements the last 10-15 years.

Analysing macro-economic effects of alternative scenarios, inputs required from the EnergyPLAN model and other analysis are:

- changes in efficiency improvements by branches and consumer category (affecting the end-use demand for energy)
- investments split between the energy sector, other branches and households
- changes in energy prices

Inserting these changes into ADAM/EMMA gives an alternative economic development and macro-economic effects are analysed comparing the economic development to the reference scenario.

The purpose of the first exercise is to indicate a level of macro-economic effects of changing the energy-system and to reveal lack of information and problems in implementing alternative energy scenarios in ADAM/EMMA. For the final calculations, both the model, the reference economic development, and energy prices are changes. At present ADAM/EMMA is modelled in constant prices. However, as the national account is changed to chain-indexes the model is at present under revision – expectedly with a revised categorisation of branches and consumer categories.