Model for a Sustainable Energy Supply for Austria

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Abstract

In many countries such as Austria the energy demand is mainly covered by fossil fuels. The negative impact on the climate and their decreasing availability brings up the need for a shift to a possible future energy system using solely renewable energy sources.

The goal of the modelling is to compare and possibly match the energy demand of Austria with the long-term potentials of Austria's renewable energies. In different scenarios possible ways of covering the energy demand should be visualised and analysed, taking into account the necessary use of biomass for food, for animal feed and for products.

To reach this goal a static model of the demand in all different energy sectors versus all the various energy sources available per year was developed. Many parameters allow to change settings on both sides for the scenarios easily. We use a top-down modelling approach for the energy balance and apply bottom-up approach for functional modelling of the important parts of the system, due to high energy consumption, efficiency or trade-off potentials. Via the applied parameters it is possible to examine the effects of enforcing or reducing various energy supply and energy conversion technologies.

Our conclusion is that - against common opinion - it is possible to provide full coverage of Austria's energy demand by just using renewable energy sources, even with the still existing technologies. However significant changes in the structure of buildings and in the transportation means are necessary. Introducing high construction standards leads to a definite reduction of heat losses. Room heating can then be done preferably by solar collectors, heat pumps and low-temperature district heating, reusing industrial waste heat wherever possible. The main part of biomass should be converted in CHP to process heat. The mobility structure has to change towards electrically driven technologies with much higher conversion efficiencies.

Keywords: Sustainable energy system, renewable energy sources, energy systems model, efficient technologies

1 Introduction

In these days the topics Climate change, high oil prices and rising food prices illustrate the dependence of many industrialised countries on fossil fuels mainly used as energy carriers. To mitigate the impacts of climate change, to increase national or regional value creation or the security of supply; the necessity for a sustainable energy system is discussed intensely by the science, by national and international policy makers and by economic and non economic stakeholders.

All the future scenarios of the energy demand are based on the actual demand, which developed as a result of cheap fossil resources and their broad availability. Extrapolation of the recent development to future trends leads to immense high energy demand scenarios for future which cannot be covered by renewable energy carriers. But in the long term it is unavoidable to use renewable sources only.

This paper examines the opportunities of energy supply of the Austrian economy on a solar basis and shows up, which changes have to be made to be able to meet the demand of the different sectors. With realistic available renewable energy potentials and foreseen technological improvements ways of possible full coverage of the energy demand are analysed in scenarios. The basis for this research is the Austrian energy balance. Fossil energy carriers are replaced by renewable energy forms and in a first step the insufficiencies are identified. Then the technological measures and required structural changes are implemented, which seem to be able to lead to a full coverage of the demand.

The results should point the reasonable development tracks which would be needed for a conversion to a solar based energy system. They should mark a possible vision of a sustainable energy future for Austria. Hence a specified time frame, costs or social acceptance are not considered. But they should be discussed on the basis of the results.

2 Methodology and approach

In course of the project a model was developed that provides the opportunity to analyse possible options of full coverage of Austria's energy demand solely by renewable resources. We used the modelling tool GABI, an object-oriented software tool that allows functional programming of process models. The objects can be taken out of databases or defined by the user. There exist different object categories, as the most important processes, flows and plans. The processes, which contain data of their input- and output-flows are positioned on the plans and then connected by the flows to process chains.

The model provides for the combination of different conversion technologies to cover the energy demand with the available potentials. "Distribution links" allow to reduce or enforce the use of certain technologies and to simulate the effects on the economy wide energy system. In sensitivity analyses the importance of the different "setscrews" then can be proved.

The basis of the modelling is the Austrian Energy Flow Diagram shown in figure 1 in a simplified version. Based on the energy demand in its qualities and quantities the energy supply chains that connect the demand with the required resources are visualised. The intermediate conversion technologies are combined to fundamental blocks. The flows on the left side of these technology blocks represent the transformed energy carriers. The outgoing flows indicate the amount of useful energy. The energy loss of the conversion technologies are not visualised to increase the clarity of the figure. They are visible from the difference between the in- and outputs. The resulting figure gives an overview of the Austrian energy conversion system, its connecting flows, the conversion efficiencies and the amounts and qualities of the energy demand.

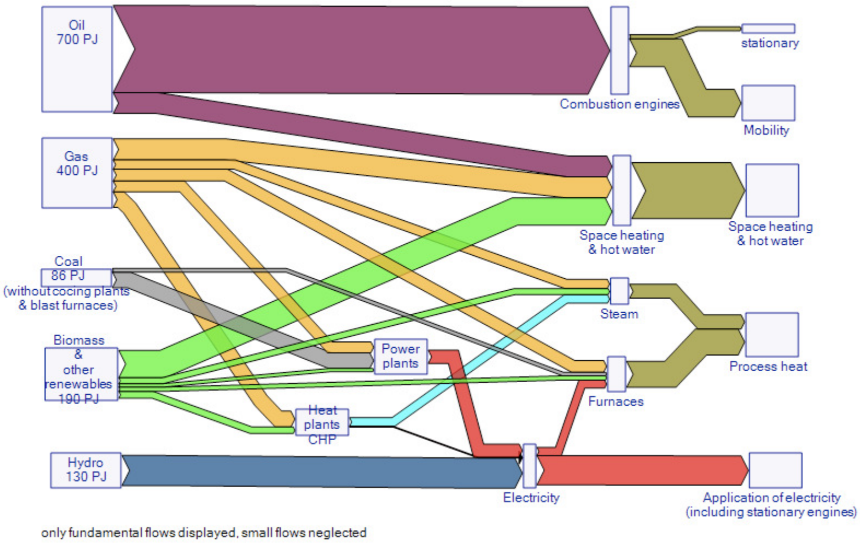

Figure 1: Austrian Energy Flow Diagram 2005 (simplified)

The now existing energy system is based on the use of mainly fossil resources. Mobility, space heating and process heat dominate the demand. For the electricity supply hydropower is yet the most important technology. The biggest losses occur in mobility followed by space heating.

3 Renewable energy potentials

Biomass for energetic and non-energetic use is obtained by agriculture and by forestry. Agricultural area can be divided into grassland, which is mainly used to provide animal feed, and cropland, used to cultivate plants for food, animal feed and products. Assuming the same amount of non-energy carriers produced in Austria as in 2005, only about 7 PJ of first generation biofuels seem achievable on the cropland, due to small area potentials available. Forcing biological agriculture on the grassland would make it possible to use more areas in the mountains for raising animals. The grassland and the dung of animals in lower regions can then be used to provide biogas purified to natural gas quality of about 80 PJ yearly.

This potential calculation is based on specialised agricultural systems. Using integrated biorefinery systems a potential of about 180 PJ yearly seems achievable without any negative implication on the production of food and feed according to Amon [1].

The forest and the landscape conservation are the main sources of wooden biomass. From these sources different qualities of wood can be achieved. While the landscape conservation brings mostly wood for energetic use, the forest provides raw materials for the wood processing and the paper industry. In these days about 25 % of the required wood in Austria has to be imported. For the modelling of the wooden biomass potential the imports and exports of wooden raw materials and wood products are not considered. Nowadays about 60 % of the growth of the Austrian forest is used. This amount is raised to 85 % in this study. Assuming the same production characteristic for the wood processing and the paper industries as in 2005 a potential of 98 PJ of wooden biomass for energetic use is achieved, containing firewood and waste of the wood processing industry. Reusing 60 % of the resulting wood products after their lifetime and using the resulting black liquor of the pulp process energetically can then account for about 44 PJ yearly. This brings a potential of 142 PJ of wood based energy carriers yearly.

The potential of electricity gained by photovoltaic (PV) depends on the technology used, the respective solar radiation and the total area of installations. High potentials of PV without any further use of landscape are foreseen for building integrated solutions. Therefore in the model the area of roofs on buildings is the major basis for calculating the potential of PV. The buildings are modelled on the demand side for calculating the amount of space heat demand. The energetically usable roof area on these buildings is assessed and dedicated to PV (about 60 %) and to solar heat (about 40 %). Using 75 % of the available roof area and calculating 316 kWh/m^2*a as possible specific yield foreseen for PV the next decades in Austria leads to 70 PJ electricity yearly. Furthermore PV on facades and PV plants, that follow the sun automatically are considered, but provide smaller electricity potentials due to low specific yields or few dedicated area. Altogether an electricity potential of 94 PJ yearly out of PV is calculated. Using also surfaces on other constructions would lead to an even higher potential.

Solar heat for providing space heat is calculated via the area on roofs available, as mentioned above. A specific yield of 400 kWh/m^2*a for flat plate collectors and using about 40 % of the available area potential leads to about 60 PJ space heat yearly. Solar heat to provide process steam can be used wherever temperatures below 200 °C are required. In Austria this is about 25 PJ yearly [2].

The potential of hydropower is based on the technical economical potential of 56.100 GWh/a (200 PJ) indicated in different studies, i.e. Pöyry [3]. The framework directive in the field of water policy of the European Parliament has not been considered in any of the potential studies. Therefore the potential for this study is reduced to 150 PJ per year.

A study on the electricity potential using wind power in Austria in the year 2020 by Hantsch [4] resulted in 26 PJ yearly. The study calculates an amount of about 1.000 possible plants. Assuming, that 1.300 plants are possible in Austria and a mid to long-term average plant power of 6 MW leads to a potential of 59 PJ yearly.

Due to the limited potentials of renewable energy carriers the main issue of the transformation into a solar-based energy system is to use the existing potentials as efficient as possible. The priorities in this context examined in this study are the following: solar heat for space heating and hot water and in industry wherever possible. Wooden biomass should primarily be used in combined heat and power (CHP) plants to provide process heat or in industrial furnaces wherever possible.

A compilation of the respective potentials in Austria is shown in the following figure 2. The fossil energy carriers are removed and hence the supply side includes only renewable energies.

The size of the flows account for the amounts of energy potentials calculated. In the case of biogas and PV the squares and the flows arising from it have different sizes. In these areas it seems possible to further increase the potentials as described.

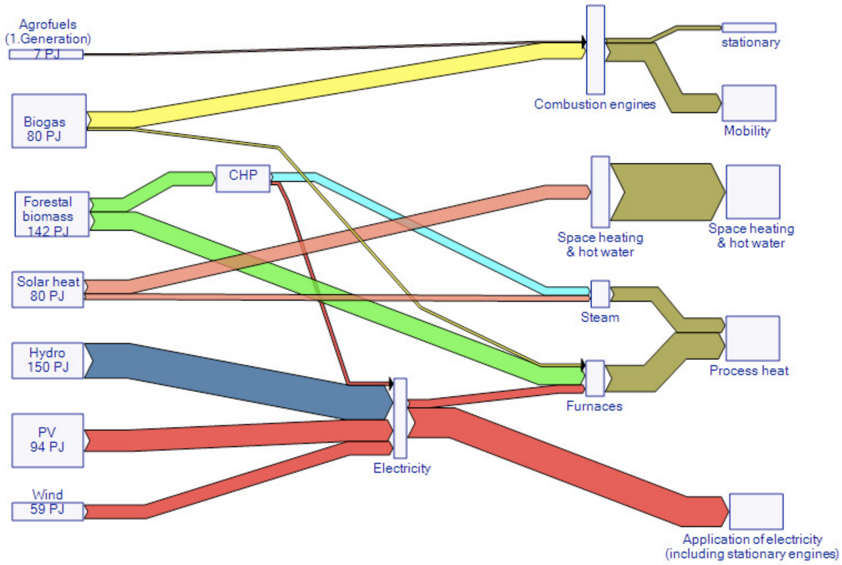

Figure 2: Solar and biogenic potentials

A shortage of energy is clearly visible above all in the mobility and space heating areas. The potentials of biogas and liquid biofuels are not sufficient to cover the existing demand of the corresponding fossil energy carriers. Even dedicating all biogenic fuel potentials to the transport sector would not solve the problem.

Also in the area of space heating and warm water only by solar heat it is not possible to cover the existing demand. The forestal biomass, which is actually an energy carrier for space heating, is assigned to provide process heat, because there are little alternatives in industry imaginable. This way the process steam demand can be covered. The technical feasibility of using biomass in industrial furnaces has to be further analysed. In cases where this is not possible a substitution of electricity for fossil energy carriers represents a technical solution as this is already realised in parts of the metalworking or glass industry.

The electricity demand of stationary drives, of electrochemistry, of the households and for computing and illumination is combined in "application of electricity", due to the exclusive use of this energy carrier. The potentials of electricity out of renewable sources are much higher than required for these applications, which allows to supply also parts of the industrial furnaces and other areas of demand for electricity.

4 Changes in the means of transport

As shown it is not possible to cover the existing energy demand for transportation just by a substitution of biofuels for fossil energy carriers. Hence it is necessary to work out realistic possibilities of structural changes that can lead to a full coverage in this area.

Electric drives offer much higher conversion efficiencies than combustion engines. Thus combustion engines should be substituted wherever possible: local traffic up to 50 kilometres is realised in this study by electrically driven bicycles, scooters and cars. Public transport of short distances is realised by subway, tramway and electrically driven buses. Distances below two kilometres are realised mostly by foot or by bike. Distances over 50 kilometres are realised by railway and private transport with biofuels and biogas. The individual long distance traffic is partly shifted to the railway. For the rest a supply with biogas and biofuels is assumed. Transportation of cargo is mostly shifted to railway. The rest as well as short distance distribution of cargo is covered by biogas and biofuels.

These changes have great impacts on the demand structures. The energy demand for local traffic is reduced drastically through the much better conversion efficiencies of electric drives. Long distance traffic overall the cargo transportation by train reduces the energy demand extraordinary and can then be covered by the potentials of electricity.

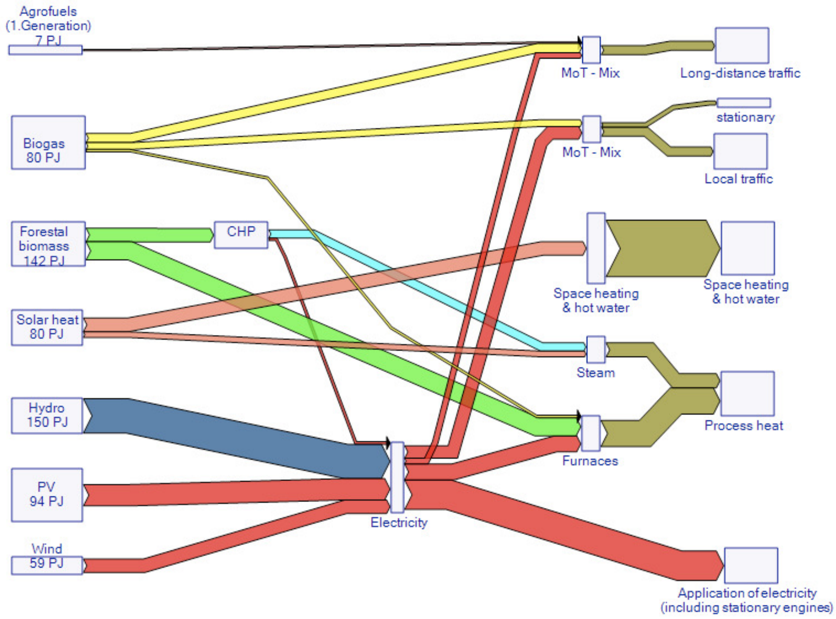

Figure 3: Changes in the means of transport

5 Changes in the space heating demand structure

In Austria the average heat demand of the existing residential buildings is 140 kWh/m^{2}a [5]. Considering the technological construction possibilities a significant reduction of the heat demand is possible. For the study we applied an average heat demand of about 50 kWh/m^{2}a over all buildings (including non residential).

Covering the resulting demand would be possible with the following technological opportunities: In rural areas solar heat and heat pumps are used for space heating and hot water supply (low temperature heating). In urban regions the main part of the supply is realised via district heating including industrial waste heat.

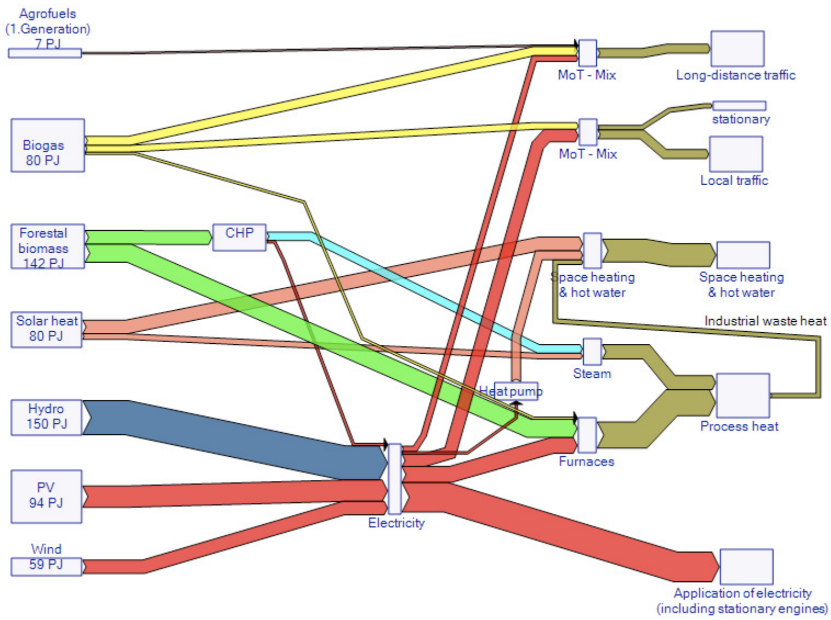

Figure 4: Full coverage by changed demand structures

6 Results

As a major pillar for a solar based energy system for Austria electricity has to become the basic energy carrier. The biggest potentials mainly in decentralised technologies would need a significant change of the power grid management. The major power supply would then come from decentralised small scale suppliers, the existing companies of the energy sector should then concentrate mainly on grid management, to compensate differences between supply and demand, instead of electricity supply with power stations.

Covering the energy demand in industry seems possible with the potentials of forestal biomass and by substituting fossil based melter furnaces by electric furnaces. The technological feasibility of this substitution has to be further analysed. Solar heat applications in industry should be pursued wherever possible.

The introduction of high construction standards will lead to a reduction of heat losses in buildings drastically. The resulting demand then can be covered by low temperature heating systems. In rural areas the potentials of solar heat and heat pumps allow full coverage with these technologies. In urban agglomerations district heating using preferably industrial waste heat and additionally solar heat and heat pumps can satisfy the demand.

In transport combustion engines are the dominating technology nowadays. The low efficiency of these engines leads to a high energy demand of mainly fossil fuels. Introducing electric drives and providing varying transport technologies for different distances allows a full coverage in transportation. Local traffic with mainly electric drives would allow covering the demand out of local supply. Long distance traffic has to shift partly to the railway. Parts of it can be covered by the potentials of biogas and liquid biofuels. Long distance cargo transportation has to shift significantly to the railway to make full coverage in transportation possible.

The displayed opportunities of a full coverage of the Austrian energy demand out of renewable sources should characterise the reasonable development paths obeying the realistic renewable potentials. They should mark a possible vision of a sustainable energy future for Austria without considerations on how the shift could be implemented.

Framework

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