Regionalized Global Energy Scenarios Meeting Stringent CO_2 Constraints – Cost-effective Fuel Choices for Transport

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Abstract The aim of this study is to analyze the world's future energy supply, in general, and cost-effective fuel choices in the transportation sector, in particular, under stringent CO_2 constraints. The analysis is carried out with the help of a global energy system model GET-R 1.0, developed specifically for this project. It is a linear programming model and it has three end-use sectors: electricity, heat and transportation fuel. It is set up to generate the energy supply mix that would meet exogenously given energy demands at the lowest global cost. We have chosen an upper limit on CO_2 emissions corresponding to an atmospheric CO_2 concentration target of 400 ppm, by the year 2100. We find that it is cost-effective to carry out the transition from gasoline/diesel in the middle of the century and that hydrogen becomes the most cost-efficient fuel in the long run. Within the electricity production sector all renewable energy sources show a pattern of increasing contributions during the century and solar produced hydrogen will dominate by year 2100. Biomass is the dominant fuel in the heat sector. Further, we compare our results with those generated using a globally aggregated version of the model. We find that the regionalization only marginally affects the general pattern.
Keywords Energy scenarios Climate target CO_2 Alternative transportation fuels Hydrogen, Biomass

1 Introduction

Currently, 80% of energy used is based on fossil fuels and substantial reductions of the global CO_2 emissions are required in order to minimize risks of severe climatic changes, but this would involve considerable changes in the present energy system. To stabilize the atmospheric CO_2 at 400 ppm, which might be an acceptable level[3], global CO_2 emissions need to drop from 6 Gton C/yr to around 2 Gton C/yr, by the year 2100[5]. This study explores the possibility of combining increasing energy demand with strong reductions in CO_2 emissions over the 21st century.

The transportation sector has a negative impact on local air quality and is a major emitter of CO_2, and it is being discussed which fuel should be used in the long run, when there are stronger restrictions on CO_2 emissions.

The purpose with this study is to analyze cost-effective fuel choices in the transportation sector, under stringent CO_2 constraints, and to investigate whether regional differences in energy supply potentials may result in differences in fuel choices. More specifically, we ask the following two questions:

1. when is it cost-effective to carry out the transition away from petroleum based fuels in the transportation sector?
2. to which fuel is it cost-effective to shift?

Model and scenario assumptions are presented in section 2 followed by global results presented in section 3. The results are discussed and conclusions are drawn in section 4.

2 Model and scenario assumptions

2.1 Model description

A globally aggregated energy system model (GET 1.0) has been developed in year 2000 by Azar, Lindgren and Andersson[1]. In this study, we have regionalized this earlier model into eleven geographically different regions (GET-R 1.0). These new scenarios will show how each region can meet its energy demand, and thereby give a better understanding of the prospects for changes in the global energy system.

GET-R 1.0 is a linear optimization model designed to choose primary energy sources, conversion technologies and transportation technologies that meet the energy demands of each region, at the lowest aggregate costs, subject to a carbon constraint (a tax or an emission cap). In this study, the only environmental concern is CO_2 emissions and we do not consider local air pollutions or energy security. Energy supply potentials and the demand for electricity, heat and transportation fuels, are exogenously given. The transportation sector is disaggregated into cars, trains, buses, trucks, ships and air planes whereas the electricity and heat sectors is analyzed in aggregate. Primary energy supply options, the three energy demand sectors and fuel choices in the transportation sector, are presented in Figure 1.

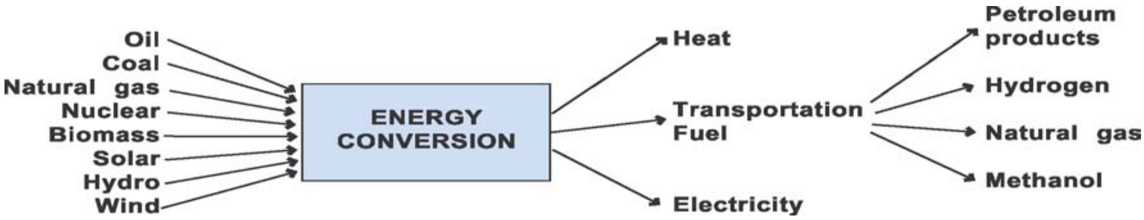

Figure 1: The basic flow chart of supply and fuel choices in the energy system model.

2.2 Energy demand

Regional population, heat and electricity demand are assumed to follow an "ecologically driven" scenario developed by International Institute for Applied Systems Analysis (IIASA) in Austria. In this scenario, titled "C1", it is assumed that technological development leads to energy efficiency improvements[7].

In all regions, per capita income increases and transportation demands are assumed to follow regional developments of GDP. Public use of aviation are assumed to increase rapidly and domestic motor vehicle use is also assumed to strongly increase, especially in the developing countries. Assuming a global population of 10 billion, a total of 5 billion cars are assumed to exist by the year 2100. The global density of cars is then 0.5 cars/capita, which is the current car density in Germany. More details are given in Azar et al, 2000[2].

2.3 Energy availability and conversion

Regional oil and gas supply potentials and the annual hydro and biomass supply are assumed to follow Johansson et al, 1993[6]. Regional coal maximum supply potentials are assumed to follow Rogner, 1997[8]. Biomass is limited upwards to around 200 EJ/yr[6]. This constraint has important implications since the total energy demand is much larger. Thus, the model chooses to use biomass in the sector where it is most competitive. Efficiency of energy conversions, cost of industrial plants, vehicle engines and fuel infrastructure are discussed in detail in Azar et al, 2000[2].

3 Results

Due to space limitations, it is only possible to present a short summary of our results here. A more complete description can be found in Grahn et al, 2003[4].

3.1 Primary Energy Supply

A scenario displaying primary energies to supply the global energy demand is presented in Figure 2.

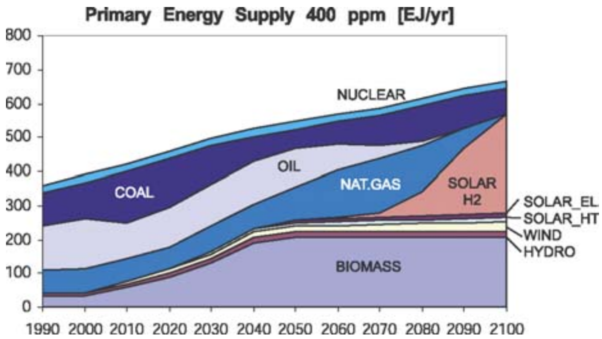

Figure 2: Primary energy sources chosen to supply the world's energy system, if atmospheric CO_2 concentrations are stabilized at 400 ppm. The eleven regional results have been added to produce this global figure.

Over the next fifty years, the model suggests that a rapidly increasing supply for biomass is a cost-effective way of meeting ambitious climate targets. The use of oil and gas remains roughly constant until they become exhausted. The use of coal remains possible since carbon capture and storage technologies are used on a larger scale, from the middle of the century and onwards. Of the three solar energy technologies in this model, solar energy for electricity production and solar energy for heat production remain at about the same level as wind and hydro, but solar energy for hydrogen production increases rapidly during the second half of the century.

3.2 Transportation

A scenario describing cost-effective fuel choices in the transportation sector is presented in Figure 3.

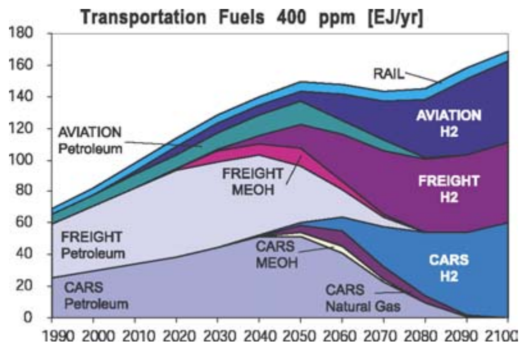

Figure 3: The most cost-effective fuel choices suggested by GET-R 1.0 if atmospheric CO_2 concentrations are stabilized at 400 ppm. Note that regional results are added to give a global figure.

In cars and freight subgroups the model suggests a transition from petroleum-based fuels in internal combustion engines to hydrogen used in fuel cell engines. Some methanol in internal combustion engines is shown in a transition period in both sectors. The model also presents natural gas as a cost-effective transition fuel in subgroup cars. In aviation, the model shows a transition from fuels based on oil towards liquefied hydrogen.

3.3 Heat and Electricity Production

The model suggests that biomass and coal will dominate as primary energy source for heat production. Model result for electricity production shows that oil is phased out early. Coal, which dominates the first two decades, decreases but increases again by the end of the century due to the fact that decarbonization techniques become cost-effective and used on a larger scale. When solar based hydrogen is introduced by the middle of the century it will rapidly increase its share and dominate as a primary energy source in year 2100. Biomass, as well as wind and hydro power, displays an increasing pattern throughout the century. Natural gas is used for power production on a large scale until it declines by the end of the century due to lack of availability. Result figures are presented in Grahn et al, 2003[4].

4 Discussion and Conclusions

Below, we summarize our results and offer some explanations for them.

4.1 Oil remains dominant in the transport sector for several decades despite stringent climate targets

A perhaps somewhat surprising result from our modeling exercise is that oil remains dominant in the transport sector several decades ahead. A physical explanation for that is that known oil and natural gas reserves, contain about 200 Gton C. Since we allow 500 Gton C to be emitted between 1990-2100, it is possible to release more CO_2 emissions than what exist in the total reserves of oil and natural gas, and still stabilize the atmospheric CO_2 concentration at 400 ppm. The advantages of using oil in the transportation sector is larger than using oil for heat or electricity production.

One tempting interpretation may be that no new technologies would need to be developed until the middle of the century, but to make the transition to hydrogen in the transport sector possible around 2030 – 2050, hydrogen need to be used in vehicles before 2030.

4.2. Hydrogen and not biofuels become the dominant transportation fuel in our model

Hydrogen becomes the dominant fuel in the transportation sector, as it is more cost-efficient to use biomass for heat production. Using biomass to produce methanol would imply that the heat demand would have to be satisfied from other CO_2-neutral sources, which would increase the overall cost of the model. The reason why biomass can not be used for both heat and transportation is that the overall supply is limited upwards due to availability constraints.

4.3 Model results are not a prediction of the future

The purpose of this study is not to predict the future. This exercise illustrates the most cost-effective solution to supply the energy demand under the constraint that atmospheric CO_2-concentration should be stabilized at 400 ppm. This study indicates which fuels and technologies are most cost effective in each sector, given our assumed parameter values.

We have made the observation that roughly the same cost-effective fuel choices in the transportation sector are shown in this regionalized version compared to the globally aggregated model.

One general result from our study that is less dependent on the actual parameter choices is that it is possible to combine ambitious climatic goals with an increased demand for energy services.

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