Possibilities to include rebound effects in energy scenarios

Tobias Naegler, German Aerospace Center (DLR), Institute of Technical Thermodynamics, Department of Systems Analysis and Technology Assessment, Stuttgart, Germany, Email: tobias.naegler@dlr.de

What is a scenario?

Energy scenarios describe possible, consistent pathways of the future development of the energy system, i.e. the future development of energy consumption as well as energy supply. Scenarios are no forecast – they do not try to predict the most likely development of the energy system. Therefore, they do not necessarily explicitly include feedbacks between energy consumption, energy efficiency, energy supply, economic productivity, level of consumption etc. Scenarios rather explore different thinkable outcomes that might result if basic assumptions are changed. Consequently, scenarios often focus on the *comparison* of different options for the future development of the energy system in terms of necessary structures of the energy system, infrastructure demand, security, and costs of energy supply, environmental issues etc. as well as the basic political decisions and measures that have to be taken.

Energy scenarios at the DLR

Scenarios often focus on certain aspects of the energy system. The scenario models at the DLR particularly analyse the potentials of renewable energies for power and heat supply as well as the deployment of renewable energies in the transport sector. Prominent examples are the national "Leitstudie" for the German Ministry for the Environment and the global "Energy [R]Evolution" scenarios for Greenpeace and EREC (the European Renewable Energy Council). The latter scenario also has been featured in the IPCC's Special Report on Renewable Energy Sources and Climate Change Mitigation (SRREN).

The simulation of the energy demand in the different sectors (households, services, industry) usually relies on results of other, more detailed models or studies on the energy demand in particular sectors as input for the complete scenarios. Thus, there is no direct coupling between efficiency measures and demand in the sectors and in particular not between different sectors. Therefore, the DLR scenarios do not aim at quantitatively discuss the effects of political energy efficiency measures on the energy demand but try to follow consistent and plausible development paths of energy intensities. Furthermore, in the latest "Leitstudie" the scenarios take into account the political targets for energy demand and energy efficiency increase, respectively, which have been defined in the "Energy Concept" of the German Government. Therefore, these scenarios implicitly assume that all necessary measures have been taken to achieve the targets set in the "Energy Concept".

When modelling different scenario variants, e.g. different targets for CO_2 emissions for a given time horizon with different penetrations of renewable energies in the energy market and different pathways of efficiency improvements, generally an *identical* set of boundary conditions for all variants is chosen. These are for example the development of the population, estimates of the development of the living space, the demand for passenger or freight traffic, the gross value added (GVA) of the industry, the gross domestic product (GDP) of the national economy etc. Thus, no feedback between efficiency improvements on one hand and the demand for goods or energy services on the other hand is taken into account. Rebound effects therefore have not been explicitly taken into account in the DLR scenarios.

Possibilities to include rebound effects in energy scenarios

Because scenarios do not intend to be forecasts, it is not necessary to explicitly include the rebound effect in a single scenario. However, in principal it is thinkable to include the rebound effect when *comparing scenario variants.* For example, a study could aim at estimating the effect of different assumptions on the future development of energy efficiency on resulting energy demand, share of renewable energies in the energy supply and greenhouse gas emissions. The first variant (lower efficiency, denoted as reference scenario REF) can be modelled without the consideration of a rebound effect. However, when computing the second variant (EFF, higher efficiency), rebound effects relative to the REF scenario can - in principle - be taken into account. However, this is only possible if reliable estimates of rebound effects are available which correspond to the model structure in terms of sectors, energy services and driving forces. This can be illustrated for the case of passenger traffic in the model:

The energy consumption of the passenger traffic is calculated in the model as follows: In the scenario REF, the passenger traffic demand (e.g. pkm, passenger kilometres) is a fixed boundary condition. Assumptions on the market shares of the different segments of passenger traffic (private cars, motorcycles, public local transport, railways, aviation) as well as assumptions on the market shares of individual technologies (in the private car segment for example diesel, gasoline, and biofuel cars, electric vehicles, hybrids…) within each segment allow calculating the passenger traffic demand for each technology. The total energy demand of the passenger traffic is then calculated from assumptions of the specific energy demand (in kWh/pkm) of each technology.

Ideally, technology-specific data for the direct rebound effect of the passenger traffic would be available, i.e. estimates of the change of the traffic demand (in pkm) for each technology when the technology's efficiency increases, i.e. specific energy demand (in kWh/pkm) decreases. As this can not be expected to be the case, aggregated estimates of the rebound effect on the segment level (private cars, aviation…) could be used instead. In the scenario EFF, which assumes higher efficiency levels than scenario REF, the direct rebound effect for passenger traffic could be taken into account by adjusting the traffic demand for each technology or each segment according to independent estimates of the direct rebound effect for the technology/segment in question. The combination of the adjusted estimates of the traffic demand and the higher efficiency of transport in scenario EFF then allow calculating the total energy demand of passenger transport in the scenario EFF. However, this approach requires that independent estimates of direct rebound effects at the technology/segment level of the model are available which correspond to the model's definition of energy service (here: traffic demand in pkm) and energy efficiency (here: specific energy consumption in kWh/pkm).

The case of space heating in households illustrates that the approach to include direct rebound effects in scenarios has to be adjusted to each model sector and to the degree of detail of the scenario model. In the case of space heating, efficiency improvement at different levels – thermal insulation, heating system, and renewable energies – can be considered which complicates the simulation. However, even if we focus only on thermal insulation as an efficiency measure, still the adequate definition of the energy service provided is problematic: Typically, the temperature of the interior of buildings is no model parameter, if not a complex model of the building sector is available. Instead, estimates of the development of the specific final (or useful) energy demand (e.g. in kWh/m^2 living space) are used to calculate the energy consumption for space heating. However, this parameter already implicitly includes the heating behaviour of the residents (e.g. desired room temperature, length of heating period etc.). Thus, as long as no detailed building model can be applied, a work-around is required to include direct rebound effects in the space heating sector. If we assume that the thermal insulation of buildings (in terms of the heat transfer coefficient of the building hull in W/(m^2 · K)) has increased by e.g. 10% in scenario EFF compared to scenario REF, then the specific energy demand in scenario EFF could be adjusted by a "rebound" factor which parameterises changes in the residents' behaviour . This adjustment allows obtaining an effective specific energy demand for space heating in EFF which is e.g. only 8% lower than in REF (if we assume a rebound effect of 20% for space heating).

Direct rebound effects in the in the production sector as well as indirect rebound effects could in principle incorporated into the scenario variants as increases in GDP or industrial GVA in scenario EFF compared to scenario EFF.

Summary

Scenarios are no forecasts; they merely outline possible, consistent future developments. Therefore rebound effects can be considered to be implicitly taken into account in scenarios. However, it is thinkable to explicitly consider rebound effects when *comparing two scenario variants* which are distinguished mainly by assumptions on the future development of efficiency in different sectors. The structure of the scenario model determines the requirements for independent estimates of direct and indirect rebound effects: It has to be guaranteed that the definitions of the energy service and energy efficiency in the model are consistent with the respective definitions which have been applied when estimating the magnitude of rebound effects from data and economic models.

Furthermore, it has to be taken into account that scenarios are often calculated for a time horizon of several decades. Therefore it is important to estimate the temporal development of direct and indirect rebound effects as national economies and societies evolve. And finally: For global scenarios it is important to provide estimates of the direct and indirect rebound effect not only for OECD countries, but also for non-OECD countries.