

Energy resource endowments - IMAGE

Fossil fuels uranium and fissile resources

Depletion of fossil fuels (coal, oil and natural gas) and uranium is simulated on the assumption that resources can be represented by a long-term supply cost curve, consisting of different resource categories with increasing cost levels. The model assumes that the cheapest deposits will be exploited first. For each region, there are 12 resource categories for oil, gas and nuclear fuels, and 14 categories for coal. A key input for each of the fossil fuel and uranium supply submodules is fuel demand (fuel used in final energy and conversion processes). Additional input includes conversion losses in refining, liquefaction, conversion, and energy use in the energy system. These submodules indicate how demand can be met by supply in a region and other regions through interregional trade.

Table 3.1: Main assumptions on fossil fuel resources (Rogner, 1997; Mulders et al., 2006)

	Oil	Natural gas	Underground coal	Surface coal
Cum. 1970-2005 production	4.4	2.1	1.6	1.1
Reserves	4.8	4.6	23.0	2.2
Other conventional resources	6.6	6.9	117.7	10.0
Unconventional resources (reserves)	2.9	6.9	25.0	233.5
Other unconventional resources	46.2	498.6	1.3	23.0
Total	65.0	519.2	168.6	270.0

Fossil fuel resources are aggregated to five resource categories for each fuel (see table above). Each category has typical production costs. The resource estimates for oil and natural gas imply that for conventional resources supply is limited to only two to eight times the 1970--2005 production level. Production estimates for unconventional resources are much larger, albeit very speculative. Recently, some of the occurrences of these unconventional resources have become competitive such as shale gas and tar sands. For coal, even current reserves amount to almost ten times the production level of the last three decades. For all fuels, the model assumes that, if prices increase, or if there is further technology development, the energy could be produced in the higher cost resource categories. The values presented in the table above represent medium estimates in the model, which can also use higher or lower estimates in the scenarios. The final production costs in each region are determined by the combined effect of resource depletion and learning-by-doing.

Bioenergy

The structure of the biomass submodule is similar to that for fossil fuel supply, but with the following differences (Hoogwijk, 2004):

- Depletion of bioenergy is not governed by cumulative production but by the degree to which available land is used for commercial energy crops.
- The total amount of potentially available bioenergy is derived from bioenergy crop yields calculated on a 0.5x0.5 degree grid with the IMAGE crop model for various land-use scenarios for the 21st century. Potential supply is restricted on the basis of a set of criteria, the most important of which is that bioenergy crops can only be on abandoned agricultural land and on part of the natural grassland. The costs of primary bioenergy crops (woody, maize and sugar cane) are calculated with a Cobb-Douglas production function using labour, land rent and capital costs as inputs. The land costs are based on average regional income levels per km², which was found to be a reasonable proxy for regional differences in land rent costs. The production functions are calibrated to empirical data (Hoogwijk, 2004).
- The model describes the conversion of biomass (including residues, in addition to wood crops, maize and sugar cane) to two generic secondary fuel types: bio-solid fuels used in the industry and power sectors; and liquid fuel used mostly in the transport sector.
- The trade and allocation of biofuel production to regions is determined by optimisation. An optimal mix of bio-solid and bio-liquid fuel supply across regions is calculated, using the prices of the previous time step to calculate the demand.

The production costs for bioenergy are represented by the costs of feedstock and conversion. Feedstock costs increase with actual production as a result of depletion, while conversion costs decrease with cumulative production as a result of *learning by doing*. Feedstock costs include the costs of land, labour and capital, while conversion costs include capital, O&M and energy use in this process. For both steps, the associated greenhouse gas emissions (related to deforestation, N₂O from fertilisers, energy) are estimated, and are subject to carbon tax, where relevant.

Wind and solar energy

Potential supply of renewable energy (wind, solar and bioenergy) is estimated generically as follows (Hoogwijk, 2004; De Vries et al., 2007):

1. Physical and geographical data for the regions considered are collected on a 0.5x0.5 degree grid. The characteristics of wind speed, insulation and monthly variation are taken from the digital database constructed by the Climate Research Unit (New et al., 1997).
2. The model assesses the part of the grid cell that can be used for energy production, given its physical--geographic (terrain, habitation) and socio-geographical (location, acceptability) characteristics. This leads to an estimate of the geographical potential. Several of these factors are scenario-dependent. The geographical potential for biomass production from energy crops is estimated using suitability/ availability factors taking account of competing land-use options and the harvested rain-fed yield of energy crops.
3. Next, we assume that only part of the geographical potential can be used due to limited conversion efficiency and maximum power density. This result of accounting for these conversion efficiencies is referred to as the technical potential.
4. The final step is to relate the technical potential to on-site production costs. Information at grid level is sorted and used as supply cost curves to reflect the assumption that the lowest cost locations are exploited first. Supply cost curves are used dynamically and change over time as a result of the learning effect.

A brief overview is presented here, for more information see the [IMAGE 3.0 web page](#).