Invited paper, IPCC Expert Meeting on Mitigation and Stabilisation Scenarios, Copenhagen, 2-4 June 1999

LOW ENERGY CONSUMPTION SCENARIOS

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ABSTRACT

In a project performed for the Danish Energy Agency (Sørensen, Kuemmel and Meibom, 1999), four global energy supply scenarios with zero greenhouse gas emissions have been constructed, based upon a common energy supply scenario. The supply scenario is constructed by a bottom-up approach, considering basic and secondary needs, development of social organisation and activities, region by region, and finally considering population growth and settlement patterns to the scenario year, 2050. The efficiency of energy conversions is assumed by 2050 to average the best efficiency in or close to the market today. Efficiency improvement is here meant to include the introduction of new technology to perform a task in a way different from the one used earlier, as well as straight improvements in the energy efficiency of a given piece of technology.

The supply scenarios comprise use of fossil fuels without carbon dioxide emissions to the atmosphere, using nuclear conversion techniques without risk of catastrophic accidents or proliferation of nuclear material, and renewable energy sources either in a purely decentralised mode, or with inclusion of some windfarms, central solar collector fields, and energy crops (although the need for such "centralised" facilities is far lower that the resources available).

1. ENERGY END USE

Several demand scenarios have been constructed for the 21st century, based either on extrapolation ("business-as-usual" scenarios) or on technically feasible, normative assumptions about the development of societies. In a greenhouse warming mitigation context, the interesting demand scenarios are those which aim at reducing emissions at a lower cost than that of supply-side measures (fuel shifts or transition to energy sources not emitting greenhouse gases). Studies have identified a number of measures not undertaken although they have no significant cost (Sørensen, 1982; 1991). The reason is inertia or opposition to "reductions" in energy use, seen as negative in the context of economic growth. As a result, measures at the supply side have been financed, that entail a higher cost per energy unit than that of suitable demand-side measures. One aim of greenhouse policies could be to change this attitude, e.g. by legislative means (such as building codes, standards for appliances, cars etc.) or by taxation (differential tax on cars and other equipment according to energy efficiency). Both types of policy means are in use in a few countries.

As an example of a demand scenario placing emphasis on demand-side measures, a bottom-up analysis based upon a vision of future global societies with high levels of prosperity will be discussed (Sørensen et al., 1999). It will be underlying the global supply scenarios to be further discussed in section 2. The assumption is, that by the mid 21st century, the average technology in use will equal the best current technology, with respect to energy efficiency. This is compounded with increasing population (using middle scenario of UN, 1996), increasing urbanisation (according to UN, 1997), and increased per capita activity level by an average factor 2.7 for energy use. The GNP activity growth factor will be larger due to the de-coupling of economic and energy growth, and the distribution between regions will not be even (because a larger growth rate is assumed for the presently poor regions).

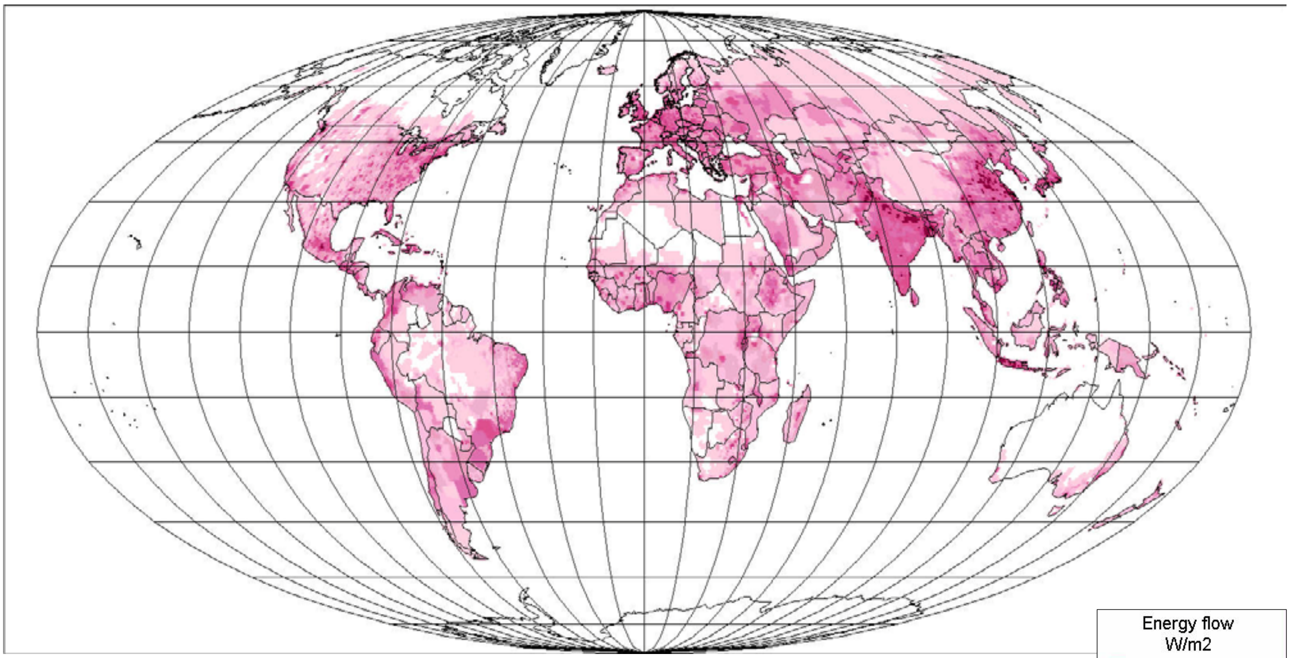
Figure1 shows the total energy delivered to the end-users in the 2050 scenario, including energy for space conditioning, process heat, stationary mechanical energy, electric energy, energy for transportation and energy in food, for all sectors of society. The average and totals for different regions are shown in Table 1, for each major energy type. The average energy demand is 0.9 W/cap. or three times the amount made useful at the end-user today. The energy made useful at the end-user today is only about 12% of the primary energy, and the challenge is to increase this fraction is the future (Sørensen et al., 1999).

In terms of full satisfaction of all primary and secondary human goals, the demand scenario assumes that for regions 1 and 2 of Table 1, there is nearly 100% goal satisfaction, for regions 3-5 some 2/3 of full goal satisfaction, and for region 6 a satisfaction level of 1/5. These levels are significantly higher than the ones characterising regions 3-6 at present, as the detailed analysis of Sørensen et al. (1999) shows.

Table 1. Energy delivered to end-user in 2050 scenario (from Sørensen et al., 1999).

Regions: / Energy quality:	1. United States, Canada	2. W. Europe, Japan, Australia	3. E. Europe, Ex-Soviet, Mid. East	4. Latin America, SE Asian "tigers"	5. China, rest of Asia	6. Africa	**Average / Total**
Food based on animals	30 45 17	30 45 24	30 45 47	25 37 52	25 37 148	20 25 51	**23 %** **36 W/cap.** **339 GW**
Food based on grain & vegetables	70 119 45	70 119 63	70 119 124	75 128 177	75 128 506	80 114 232	**77 %** **123 W/cap.** **1148 GW**
Gross transportation energy	359 136	299 158	140 146	201 277	99 392	30 61	**125 W/cap.** **1170 GW**
Heat pump input for low-T heat and cooling	103 39	110 58	87 90	43 60	80 318	22 45	**65 W/cap.** **610 GW**
Environmental heat	240 91	256 135	203 210	100 140	186 741	51 105	**151 W/cap.** **1421 GW**
Direct electric and all other energy	420 153	424 224	245 255	288 398	283 1116	47 96	**240 W/cap.** **2242 GW**
Total delivered energy*	**1272** **482**	**1252** **661**	**838** **871**	**800** **1104**	**814** **3225**	**290** **591**	**742W/cap.** **6934 GW**
Population 2050	379	528	1040	1380	3960	2040	**9340 millions**

* Including heat drawn from the environment by heat pumps.



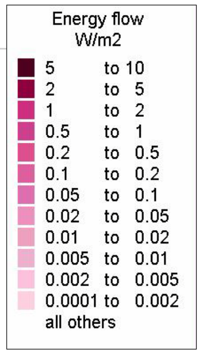


Figure 1. Total energy directly delivered to consumer in 2050 scenario (including environmental heat and the food, transportation and electricity etc. columns of Table 1). The scale of average energy flow in watts per square metre of land area is given to the right (from Sørensen et al., 1999).

2. GLOBAL ISSUES

A number of issues speak against merely optimising energy supply systems on a national or regional basis. These have to do with the cost and supply security implications of creating for some countries a dependence on resources that have to be imported from far away, but also with the desirability of preserving levels of international trade to which the economy of the currently exporting countries have become dependent.

In this chapter the distribution of different forms of energy resources are first briefly reviewed, with the purpose of identifying the possible mismatch between supply and demand on a geographical basis. Different scenarios for future energy supply systems addressing the greenhouse warming issue are then analysed with respect to their requirements for energy transmission and energy trade, with emphasis on whether the problem is local, regional or global. Finally some conclusions of possible economic and political relevance are drawn.

2.1 UNEVEN DISTRIBUTIONS OF RESOURCES

The main resources of interest for use in the energy sector, from a greenhouse impact mitigation point of view, are fossil fuels (which may be transformed to hydrogen or used with CO_2 capture), nuclear fuels and renewable energy sources. The geographical distribution of these energy sources is illustrated in Figures 2-3. In case of fuels derived from mineral deposits, the total estimated resources are given, defined as resources that are reasonable certain but independent of the cost of extraction (for specification on economic reserves of different sub-categories, additional and unconventional resources see Sørensen et al., 1999). For the renewable energy sources, land use constraints and consideration of alternative site uses and environmental impacts have reduced the estimate to an operational level.

It is seen that the nuclear and fossil resources are most unevenly distributed. The renewable energy resources are much more evenly accessible, although there are distinct variations with latitude (solar radiation) and absence of obstacles (wind power). For biomass resources, limiting factors include solar radiation, nutrients, water and soil quality.

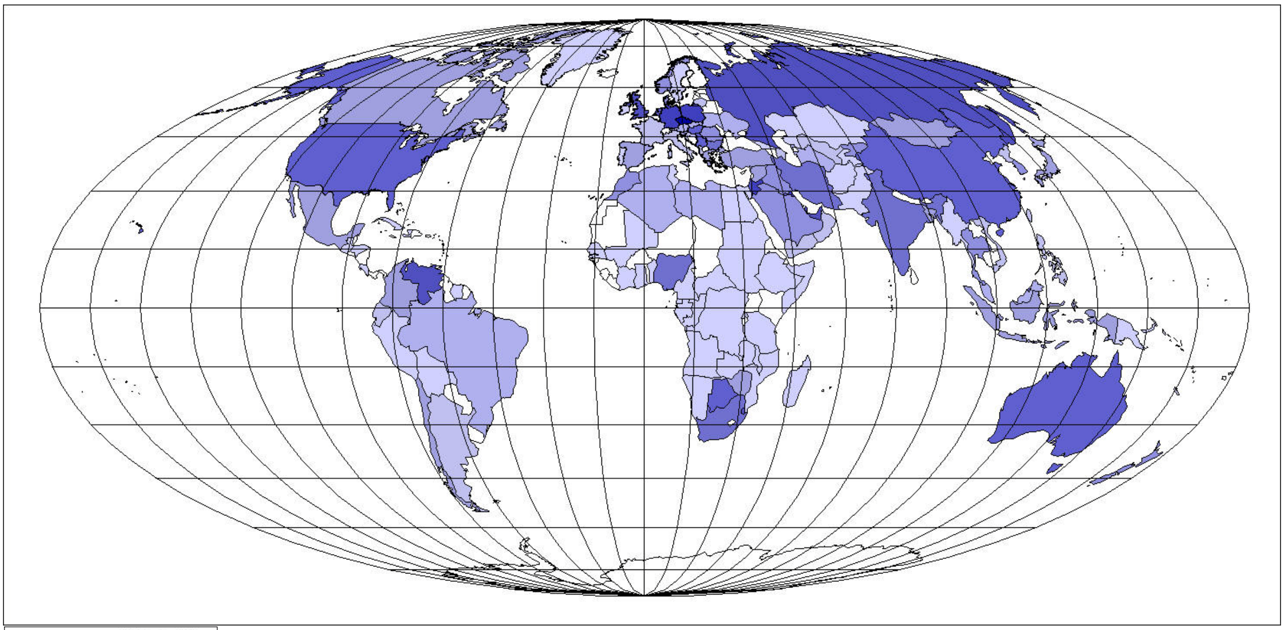


Figure 2. National distribution of fossil resources in place. Included are bituminous and sub-bituminous coal and lignite, natural gas and natural gas liquids, and oil (for off-shore resources attributed to the country of ownership). The scale given to the left uses the average number of watt-years held by each square metre of surface area (from Sørensen et al., 1999, where the distribution on individual resources and the individual graphs of reserves, possible reserves and the resource base can also be found).

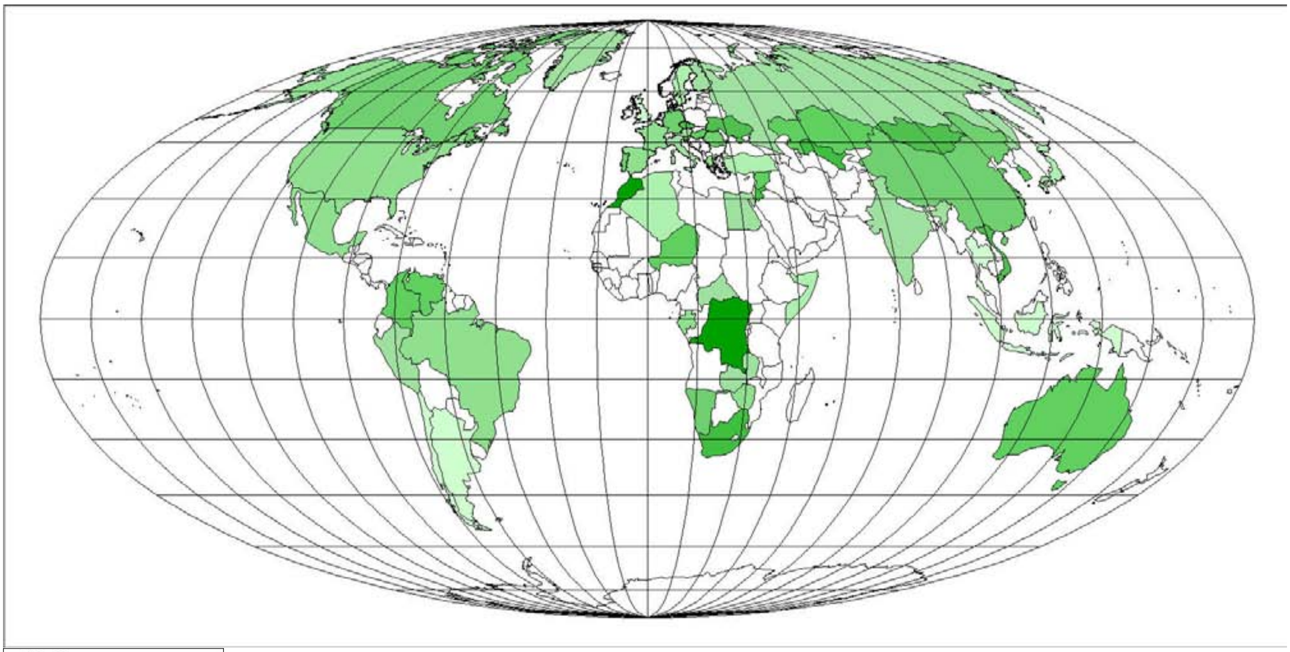
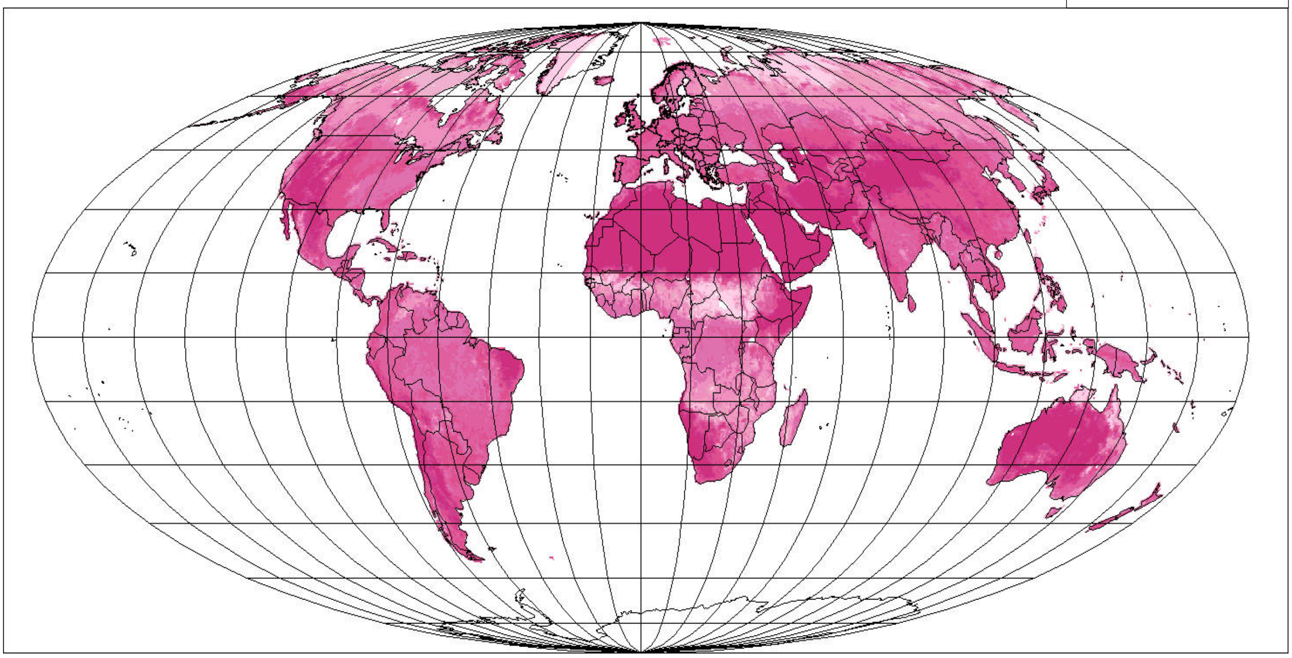


Figure 3 (above). Total estimated national uranium resources, given as average kilotons of uranium oxide per square metre (scale left). A similar amount of Thorium resources may be in place, but estimates are much more uncertain (from Sørensen et al., 1999, where also the distribution on categories of resources are available).

Figure 4 (below). Estimated total renewable energy resources, taking into account land restrictions due to alternative uses and for environmental reasons, as well as conversion losses. The sources include solar photovoltaic, wind, hydro, all for electricity, and biomass for fuels and food, given in units of energy flow (watts per square metre, scale to the right). From Sørensen et al. (1999), where details of the individual resource estimates can also be found.



2.2 SCENARIOS WITH GLOBAL OUTLOOK

Of the many energy scenarios available (see IPCC Open process, 1998), only a few are truly global scenarios addressing greenhouse mitigation issues. The recent global scenarios for the mid-21st century by Sørensen et al. (1999) specifically uses a geographical information system to display surpluses and deficits of supply over demand on an area basis (i.e. per km^2). This is particularly relevant for determining transmission and trade requirements, and this study will therefore be used in the discussion below.

The set of four emission-free energy supply scenarios are based on a common energy demand scenario, described above in section 1. In this way the four different supply options selected (clean fossil, safe nuclear, decentralised and centralised renewable energy) can be compared on a common basis. This of course does not mean that the actual future energy system may not be a combination of the options. The scenarios are briefly characterised as follows:

1. *The clean fossil scenario*, with new fuel cycles avoiding or retaining greenhouse gases for deposition or other uses not leading to atmospheric release.

2. *The safe nuclear scenario*, with new fuel cycles minimising proliferation possibilities and risks of large accidents, and aiming at delivering energy for other energy use sectors besides that of electric energy, without long-term waste storage.

3. *The decentralised renewable energy scenario*, based upon building-integrated solar systems and dispersed installations for utilising wind and biomass energy, the latter being based on integrated production of food, energy and bio-feedstock for industry.

4. *The centralised renewable energy scenario*, placing additional solar collectors or wind turbines in areas of non-arable land, or off-shore in large farms. The scenario includes a cautious use of biomass plantations placed on land where competition with food production is considered minimal.

All four scenarios are found to be technically feasible and fulfilling the requirement of no net greenhouse gas emissions. However, particularly the safe nuclear and the ocean CO_2-disposal technologies, but also to some degree photovoltaic and biomass gasification technologies, are still in an early development stage, where prices cannot be predicted accurately, and where in the first two cases, environmental impacts cannot be fully assessed at the present time.

Figures 5-8 shows the distribution of mismatch between supply and demand for the four scenarios.

It is seen that for the clean fossil and safe nuclear scenarios, the countries of the world have been sharply divided into energy-exporting and energy-importing countries. The level of energy trade for the two scenarios cannot be directly compared, as the nuclear scenario values are in kilos and not energy units (due to uncertainty in future conversion efficiency). In these two scenarios, food energy is not included in the Figures, because there is no food-energy competition for land resources to resolve, as in the case of the renewable scenarios. The countries in greatest need of energy import are those with the highest population densities, having implications for the model of economic development. Because of the distance between energy surplus and energy deficit regions, there is little room for equalisation by direct transmission (of electricity, gas or heat), and energy trade will mostly have to be by ship transport over intercontinental distances (as today). The nature of the resources in these two scenarios makes the issue of local transport less interesting.

For the two renewable energy scenarios, the surpluses or deficits are much less, and even in densely populated areas such as India or China, there are areas of surplus. The deficits are of course found in highly urban areas, where high-rise buildings make the surfaces suitable for solar collectors small compared with the demand, and where wind power and biomass production is not possible. In most cases, this implies a need only for local transport or transmission of energy, from cultivated country areas or marginal land to the cities or particularly population- or energy-intensive regions, usually of modest dimensions.

Upon closer inspection of the forms of energy required, it is seen that even for the projected population increase, food supply is adequate in all parts of the world, leading only to the well-known land to city transfer, also for countries such as India and China. This is due to the scenario assumptions on improved agricultural techniques, consistent with assumptions of technological and economic growth in all parts of the world, and despite the slight decrease in yields implied by an assumed high proportion of ecologically grown food. For (bio-)fuels to be used in the transportation sector, there is a significant deficit in most of Europe, the Middle East and India, to be matched with surpluses in China, South-East Asia, Northern countries of South America and Northern countries of Asia, Europe and North America. This implies that biofuels have to be traded internationally, which is feasible as they can be transported much like oil.

For electricity, there are strong deficits in urban areas and in much of Central Europe, India and Eastern China, whereas surpluses occur in the rest of the world and for the decentralised renewable energy scenario particularly in South America. This makes the required trade in the decentralised scenario nearly impossible, unless some intercontinental electricity transmission technologies emerge. Transformation of surplus electricity to portable fuels would solve the problem, but there are barely enough decentralised resources to allow for the losses. By contrast, the centralised renewable energy scenario has additional resources from agricultural and marginal land, making trade in the form of biofuels or electricity for more modest transmission distances capable of graciously solving the problem.

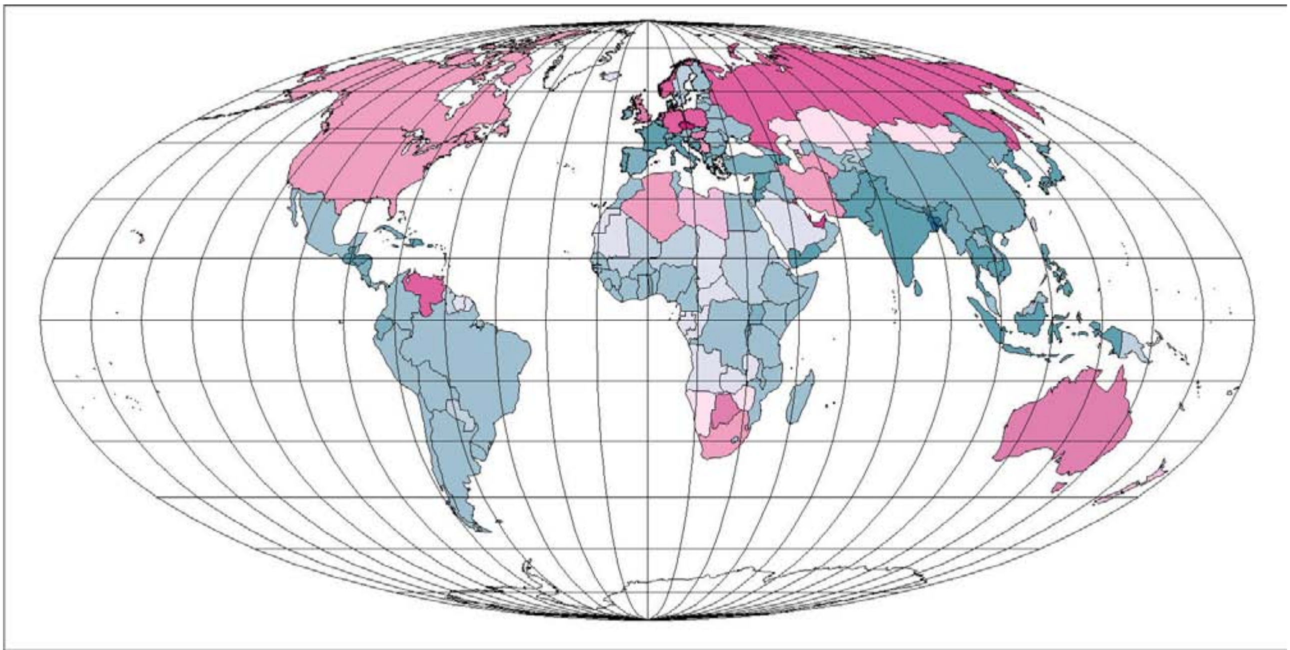
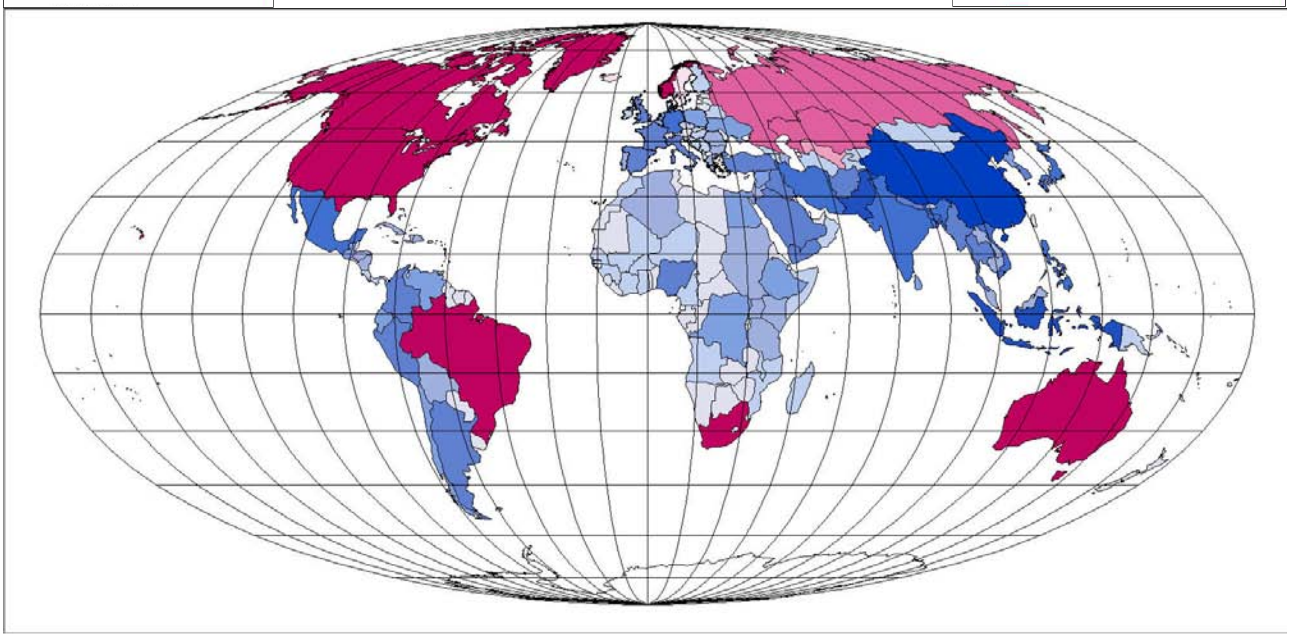
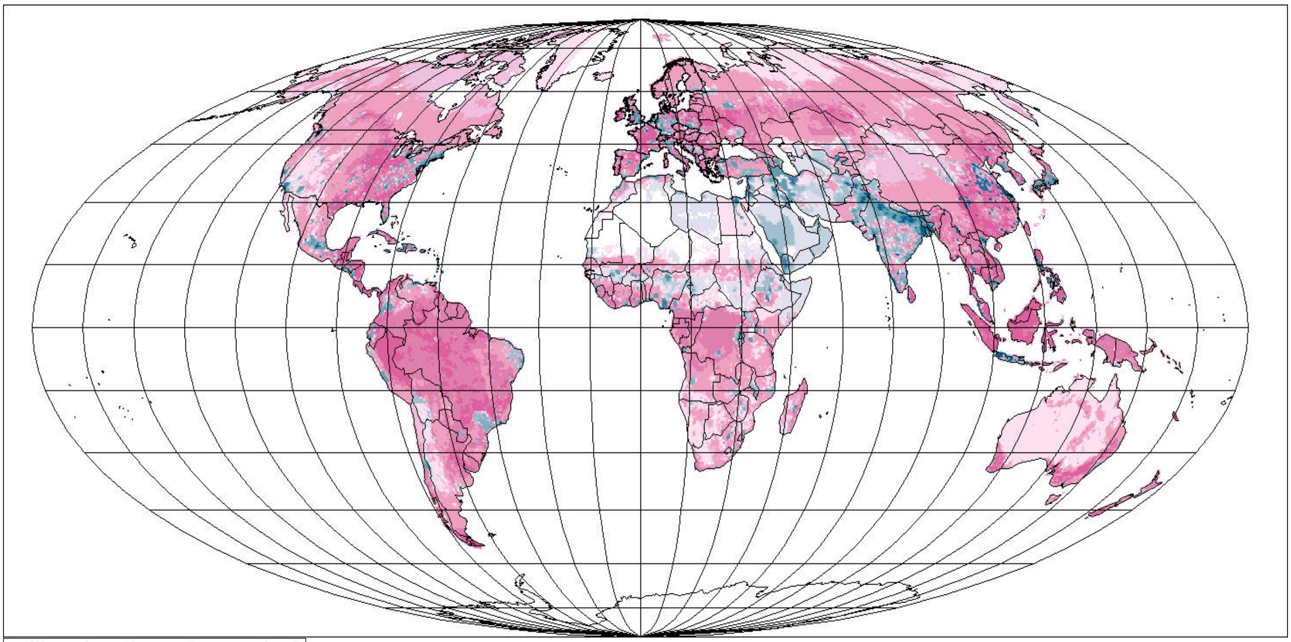


Figure 5. Difference between national average supply and demand, for the clean fossil 2050 scenario, transforming fossil fuels to hydrogen or removing CO_2 from the flue gases, and depositing the CO_2 at ocean floors (scale in W/m^2 country averages is given to the left).

Figure 6. Difference between national average supply and demand, for the safe nuclear scenario, where thorium is fissioned in a sub-critical reactor by fast neutrons delivered by a particle accelerator (scale in kg thorium oxide per year per country is given to the right).

Both Figures are from Sørensen et al. (1999).





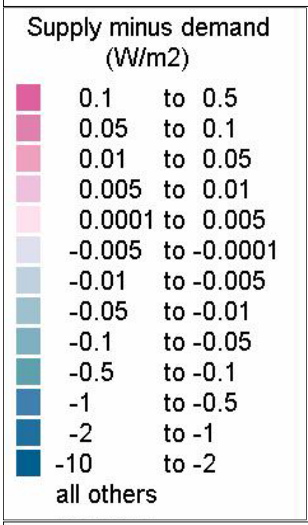
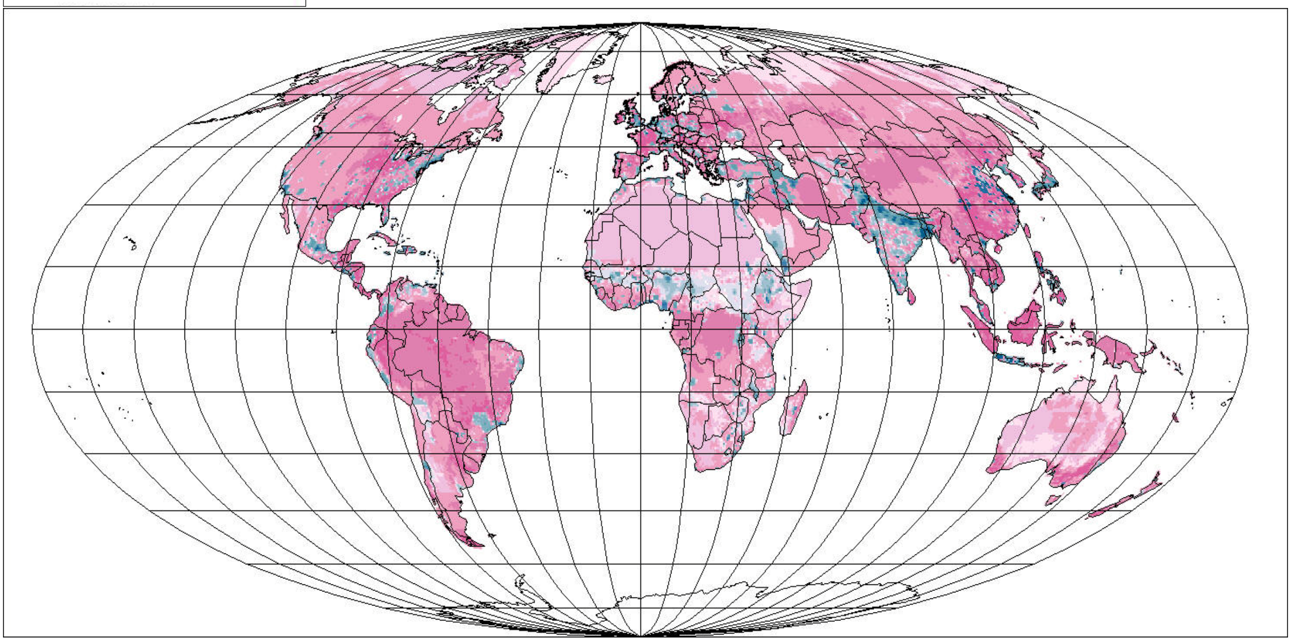


Figure 7 (above). Difference between supply and demand, for the decentralised renewable energy 2050 scenario, using only building-integrated solar cells and farm-attached wind turbines, together with pesticide-free agriculture and bio-energy production only from agricultural and forestry residues, plus existing hydro power. The delivered energy supply comprises food, electricity and biofuels for stationary and transportation uses (in contrast to Figs. 5 and 6, where food energy was not included). Scale in W/m^2 is given to the left (from Sørensen et al., 1999).

Figure 8 (below). Difference between supply and demand, for the centralised renewable energy 2050 scenario, using building-integrated and centralised solar cells on marginal land, wind turbines near farms and in parks on marginal land or off-shore, together with pesticide-free agriculture and bio-energy production from residues and a limited number of energy-crops or energy-forests, plus hydro power in place or under construction. The delivered energy supply comprises food, electricity and biofuels for stationary and transportation uses. Scale in W/m^2 is given to the left (from Sørensen et al., 1999).



2.3 IMPLICATIONS FOR TRADE AND TRANSMISSION OF ENERGY

The scenarios for clean fossil and safe nuclear energy supply entail trade and transmission of energy much in the same pattern as today. This does have implications for economic development for as well the exporting as the importing countries, where the latter may experience a slower economic growth than the one obtained with a scenario of higher self-sufficiency in energy supply.

Regarding the scenarios based on renewable energy flows of fairly low energy density, it is found that the decentralised scenario works well in some regions but on a global average basis (with the restrictions posed by renewable resources available locally and consistent with the decentralisation paradigm), it barely matches the demand of the 2050 population with the assumed massively improved living standards. This implies that the scenario requires import of energy by countries such as e.g. India, and as surpluses exist mainly in South America and is dominantly in the form of electricity, the transfer will be difficult, and seemingly in contradiction with the "local self-sufficiency" idea behind the decentralised scenario.

By contrast, the scenario adding a certain amount of centrally produced renewable energy exhibits supply in generous excess of demand, and trade of energy between regions will allow the system to be very robust against changes in assumptions such as demand development and area use. For example, desert regions in North Africa and the Middle East can export photovoltaic electric power to Europe and thereby create a basis for continued economic development without resort to oil.

2.4 ECONOMY AND POLICY OPTIONS

While the positive economic implications of adopting the energy demand scenario with high emphasis on energy efficiency is evident, the economic aspects of the supply scenarios cannot be stated with certainty. For the clean fossil scenario, the cost of CO_2 capture and hydrogen production has not been established on a realistic scale, and neither has the cost of ocean disposal of the CO_2 extracted. While these technologies are believed to be feasible, there are environmental risks associated with deposited CO_2 penetrating the biosphere, that require further studies (see references quoted in Sørensen et al., 1999). The final energy cost is believed to be 2-3 times the present, which may be acceptable in view of the externality costs of greenhouse gas emissions for the current type of energy system (Kuemmel et al., 1997).

The safe nuclear scenario is based on new nuclear conversion technologies proposed by C. Rubbia (1994). The substantial development required has so far not received the necessary support (see the discussion in Sørensen et al., 1999), and is therefore unlikely to be available in time to play a role in mitigating greenhouse impacts.

The renewable energy technologies comprise hydro and wind power, which are largely economic today, biofuel technologies currently about two times more expensive than the current sources, and photovoltaic technologies currently more than ten times more expensive than conventional coal-fired power supply. Even considering externality costs, it is therefore clear that a cost reduction is needed, and projections suggest that such a cost reduction for photovoltaic power is indeed possible and forthcoming with continued market development support. From many points of view, including (resource) sustainability and environmental acceptance, the renewable energy scenarios are the most appealing ones. The discussion in Sørensen et al. (1999) implies that the paradigm of extreme decentralisation (local or even individual control over energy supply) is not stable (e.g. towards variability between years of renewable resources) and that it requires international trade and transmission of energy of a size difficult to reconcile with the local self-sufficiency idea. The conclusion of this is that only the centralised renewable energy scenario offers a feasible sustainable energy supply system for the long-term future, and that it is indeed very likely to become feasible in the near future, adding a modest amount of centralised wind and photovoltaic energy (wind-farms on-shore and off-shore, solar cell farms), plus a modest amount of biomass crops grown for biofuels, to the decentralised renewable energy systems. It is therefore imperative, that policy measures (e.g. liberalisation of electricity trade) do not obstruct this development.

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