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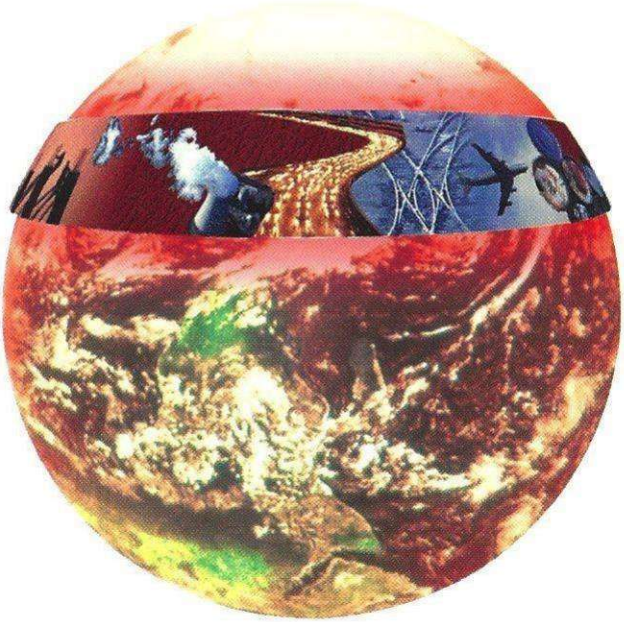
Energy systems in transition



"Man, using his muscles alone, is not a very powerful engine."
F. Braudel, The Structures of Everyday Life (1981)

13 ENERGY SYSTEMS IN TRANSITION

Bert J.M. de Vries, Arthur H.W. Beusen and Marco A. Janssen

In this chapter we present simulation experiments and outcomes of the energy submodel TIME. First, the major controversies and uncertainties are discussed. Next, the cultural perspectives are introduced with reference to world energy, after which we clarify the way in which these are linked to assumptions and model routes. Some results of sensitivity and uncertainty analyses are also given. We discuss a few energy dystopias which could emerge if, for a given population-economy scenario, the world view and the management style within the energy system are discordant. Some conclusions are presented about the plausibility of and risks related to the utopian energy futures. The impacts of the emissions from fossil fuel combustion on water, land, and element cycles are discussed in the next three chapters.

13.1 Introduction

In 1886 Jevons warned in his book 'The coal question' about the rapid depletion of British coal fields threatening the British Empire. Numerous appraisals of coal, oil and gas availability have been made since then, many of them for strategic reasons. Environmental issues and the two oil crises in the 1970s have intensified the debate on fossil fuel use. Later on, it has been broadened by incorporating demand side management and renewable supply options and by including macro-economic aspects. Controversies and uncertainties about the future development of the world energy system abound. Can energy demand really be influenced and to what extent are price changes the right instrument for this? How important are changes in life-style and in the nature of economic activities, and what is the role of technical innovation? Is the world really facing depletion of its high-quality oil and gas resources and will it show up in the form of sudden price increases and supply disruptions or will it be a smooth transition towards alternative fuels? Are the new technologies which supply energy from non-fossil sources really as promising and competitive as their advocates claim?

The major controversies relate to the question: *How can energy demand be met in an adequate and reliable way within the constraints set by socio-economic developments and goals, available energy-supply options and environmental integrity?* This formulation emphasises a few key characteristics of energy in society. First, energy is, in a variety of ways, a necessity of life which should be satisfied at such levels of cost and reliability that do not constrain human activities. In rural areas of non-industrialised regions, the emphasis is on activities like cooking, food preservation and water supply. In urbanised regions of industrialised countries, energy is also used to operate factories, heat dwellings and offices, transporting people and goods, etc. Secondly, energy has to be supplied from a variety of resources which involve a whole spectrum of technologies that require capital and skilled labour for there operation. As such, the energy-supply system is a major part of an industrialised nation's economy. Its dynamics are governed by a complex interplay between resource endowments, prices, technologies and strategic aspects. Thirdly, energy supply, conversion and use as we know it today has numerous impacts on the natural environment. Some of these have led to serious environmental damage but can be dealt with by a combination of technology, capital and political will. Other impacts, first and foremost the contribution to the enhanced greenhouse effect due to CO_2 emissions from fossil fuel combustion, are likely to be more serious and are probably less easily mitigated. The above question can be split into more specific questions:

- how will energy demand – in whatever form – develop in relation to population, economic production and consumption patterns ?
- how will technical innovations in combination with changing fuel prices affect the relation between end-use energy demand and secondary fuel use?
- how much energy from fossil fuels will be available and at what costs?
- which alternatives – for all energy forms – will be available and at what costs, and at what rate can they be expected to penetrate the market?
- should the combustion of fossil fuels be constrained because of the enhanced greenhouse effect?

In view of the transition concept introduced in Chapter 2, of special interest is the question as to which transition pathways can be envisaged from finite fossil fuel resources to non-fossil resources and technologies. In this chapter we focus on these questions and the associated controversies and uncertainties by constructing perspective-based sets of assumptions which are then explored within the framework of the energy model described in Chapter 5. First, we discuss the major issues. Although we follow a different approach for energy from the one used for water (Chapter 14), there is quite an overlap in the issues and controversies – for instance, whether the energy problem is primarily seen as a supply or a demand problem. The debate on energy, however, has a longer history and is somewhat more crystallised.

13.2 Major controversies and uncertainties

Declining energy intensity

The first item in the above list is about what will happen with the energy intensity in MJ per unit of economic activity. It has been declining in the industrialised regions but as yet it is unclear whether the underlying trends will persist. Even more uncertain is how energy intensity will change in the less industrialised regions of the world. There are strong upward pressures: the industrialisation process itself and the introduction of the 'modern' consumerist life-style. On the other hand, the availability of more energy-efficient technologies offers large opportunities to these regions for catching-up (Grübler and Nowotny, 1990).

Recent scenarios show a rather surprising agreement on the possibility to reduce energy intensity significantly. A study done for Greenpeace (Lazarus, 1993) claims that energy intensity can be reduced between 1990 and 2100 to 4.6 MJ/$, a more than threefold reduction. A possible future sketched by Kassler (1994) called 'dematerialisation', considers a similar drop to 4.5 MJ/$. A recent IIASA/WEC study (1995) gives a range between 4.6 and 7.7 MJ/$ for the year 2050. Four recently published energy scenarios for the European Community assume energy intensity to fall by 1.1 to 1.7 % per yr (EC, 1995) over the next 20 years; an inventory of analyses for the USA gives a range of 0.8-1.3 % per yr (EMF, 1996)[1]. Although one should be aware of the different backgrounds of these studies and the probability of wishful thinking and collective bias[2], it should be noted that agreement on such drastic reductions was completely absent in the early 1980s.

In a recent and fairly comprehensive overview of scenario studies made for the IPCC (Alcamo, 1995), it appears that almost all analyses assume a significant decrease in the overall energy intensity, 0.45 to 1.45 % per yr between 1990 and 2100, as a result of the three factors mentioned in Chapter 5: structural change, autonomous energy efficiency improvements (AEEI) and price-induced energy efficiency improvements (PIEEI). An overview of AEEI-values (see Equation 5.2) used in recent energy models range from 0 to 1.1% per yr in global energy models and from 1.12 to 2.85% per yr in energy efficiency scenarios (Matsuoka *et al.*, 1995). It is partly a matter of focus: "Where there is no great attention paid to energy conservation, the annual rate is between 0 and 0.5%, whereas if large energy savings are assumed, this rises to 1.0%". According to Matsuoka *et al.* (1995) the feasible range is between 0 and 1.5% per yr for the long term. One of the major controversies has to do with the effects of rising energy prices as expressed in the PIEEI-factor. Most experts agree that rising energy prices will induce energy conservation but estimates of the price-elasticity suggest great uncertainties in the rate and degree. The price elasticity is difficult to measure and differs for different sectors and countries partly because of varying substitution possibilities. It may be time-dependent, becoming smaller once more profitable measures have been taken (Dargay and Gately, 1994). Moreover, energy prices relative to interest rates and wages may actually be the relevant variable. An important role is played by government-supported research and development (R&D) programmes.

1 The larger part of this decline in energy intensity is from shifts in activity compositions and the replacement of older by newer, available and more efficient equipment; further increases in equipment efficiency and price-induced effects are minor in almost all model studies (EMF, 1996).

2 See, for example, Sterman and Richardson (1983) on the evolution of estimates of ultimate recoverable oil in the USA.

Depletion of fossil fuel resources

The second item in the above list is about the long-term supply-cost curve for coal, oil and gas. Estimates of fossil fuel resources and reserves abound in the literature (de Vries and van den Wijngaart, 1995). There is general agreement that the coal resource base is large enough to sustain present levels of production throughout the next century without major cost increases. Most researchers expect rising costs to find and produce the as yet undiscovered deposits of oil and gas but there are large uncertainties and controversies on when and how much. Estimates during the 1980-1995 period of ultimately recoverable oil and gas range from 8000 to 40000 EJ, respectively. Most estimates lack specific information on costs or probability. Nevertheless, the general attitude nowadays is that resource depletion is not an important issue anymore. One should be cautious about this because the apparent consensus may simply reflect an unwillingness to acknowledge the fact that for most countries the era of cheap and nearby oil and gas deposits to fuel industrial development is either over or will never arise.

It is known that oil shales and tar sands can provide large additional amounts of oil, possibly up to three times the conventional oil resource base (Edmonds and Reilly, 1985). For gas there is the hypothesis of huge reservoirs of pressurised gas and clathrates (Lee, 1988). Another controversial option is the liquefaction and/or gasification of coal, which could supply the world with oil and gas substitutes for a long time to come. The prospects for such conversion processes have diminished since the initial euphoria of the 1970s, and now only electricity generation through combustion of coal-based synthetic natural gas in combined-cycle plants is considered a promising option.

Alternatives to fossil fuel

Until the early 1980s the prevailing view on future energy supply was that fossil fuels and nuclear power would dominate the scene in the 21st century, although renewable energy options might play a role too. More recently, the trend towards more flexible, convenient and clean forms of energy appears to favour natural gas and new fuels like methanol and hydrogen which could be derived from a mix of nuclear and renewable sources. Nuclear energy still offers the prospect of a non-carbon energy source, but new major options for further decarbonisation are electricity from solar cells and from wind turbines. Another option to reduce net anthropogenic CO_2 emissions is the production of liquid and gaseous fuels from biomass. This could be as an expansion of present usage forms such as agricultural residues, but most of it will have to be in the form of 'commercial' or 'modern' – as opposed to 'traditional' – biofuels, in which case biomass can become a substitute for petrol in the transport sector or for coal in electric power generation.

There are still major controversies on the rate at which the costs of fuels or electricity from these supply technologies can be brought down, and hence about their penetration rate (Johansson *et al.*, 1993; Lenssen and Flavin, 1996; Statoil and

Energy Studies Programme, 1995; Trainer, 1995; Williams, 1995). First, there is the worldwide controversy on the acceptability of nuclear fission technology, which depends, to some extent, on the prospects for safer reactor designs and acceptable solutions to radioactive waste disposal. Even more uncertain is the possibility of breeder and nuclear fusion reactors. Second, most analysts agree that the large cost reductions of solar photovoltaics in the last few decades will continue, but how much the reduction for large-scale market penetration is to be is controversial and uncertain too. Third, the option of deriving liquid or gaseous fuels from biomass has rapidly gained prominence in long-term energy scenarios, but there are large uncertainties on costs and land requirements, and on the interference with food production and climate change (IIASA/WEC, 1995). There are similar controversies about the cost and acceptability of energy carriers like hydrogen and promising technologies like fuel cells, about how new supply technologies will fit in the energy system and about the efectiveness of R&D programmes. Whereas on issues of energy efficiency and fossil fuel resources a convergence in expert views may have occurred, this is less true for the role of non-fossil fuel options. In the Business-as-Usual future of the IPCC-IS92a scenario, the fossil fuel share is still 56% by 2100. The FFES scenario for Greenpeace claims that a complete phase-out of fossil fuels is feasible at an almost threefold increase in GWP per capita level (Lazarus, 1993). The IIASA/WEC study (1995) suggests that the fossil fuel share can be reduced to a maximum of 20% by 2100 in an 'ecologically driven' scenario .

Emissions from fuel combustion

Fossil fuel (product) combustion accounted in 1990 for over two third of anthropogenic emissions of CO_2, NO_x, and SO_2 (Alcamo, 1994). Future CO_2 emissions will be largely determined by the level of population and economic activity, the energy intensity and the share of non-carbon fuels. Given the previously discussed controversies and the resulting uncertainties, it is not surprising that projections of the CO_2 intensity in 2100 ranges from 105% to 10% of its 1990 level (Morita *et al.*, 1995). In view of the relative scarcity of low-cost oil and gas *vis-à-vis* coal, many official forward projections indicate an increase in coal use and in CO_2 emissions. If such a future unfolds, the need to take action beyond a 'no regrets' strategy will become more pressing. Removal of CO_2 from exhaust gases could become one of the necessary responses[3]. For NO_x, and SO_2 there is a variety of emission abatement options, but their introduction will often depend on regional circumstances.

Despite the controversies and uncertainties, there is a widely held conviction that the world energy system will undergo a transition over the next century. Most of the

3 CO_2 removal may become feasible in the future for large-scale combustion processes (Blok *et al.*, 1993). It is not considered in the present model.

above elements will be part of it, but it is difficult, if not impossible, to predict their relative importance. A final set of questions relates to the feasibility of such an energy transition from a macro-economic point of view. Future expansion of the energy system will require enormous investments, an increasing share of which will be needed in the presently less developed regions (Dunkerley, 1995). Capital and/or energy shortages may become a constraint to economic growth if the proportion of electricity increases and capital-intensive options like nuclear and solar power get a larger market share. On the other hand, important learning effects and an increasing share of capital-extensive biofuels may mitigate this problem. Evidently these issues are hard to resolve in the face of large uncertainties on capital markets and technological performance. Another constraint may be posed by land in case of large-scale introduction of biomass-based fuels : a sizeable part of presently cultivated land may be needed.

13.3 Perspectives on world energy

Given all these controversies and uncertainties, what is the use of making long-term (energy) projections? As has been set out in Chapter 10, we will attempt to address this problem by formulating coherent sets of assumptions which are considered representative for a particular perspective. The three perspectives are the hierarchist, the egalitarian and the individualist, which not only reflect a preferred way of interpreting the world, but also of managing it. Each set of world view and corresponding management styles makes up a utopia: a future in which the world behaves and is managed according to that view. In this section we will briefly – and necessarily somewhat caricaturally – describe these perspectives as far as the future world energy system is concerned (see, for example, Schwarz and Thompson (1990) and Thompson (1982)).

The hierarchist perspective

The hierarchist wishes to avoid disruptions to the smooth functioning of the energy system in view of its consequences for economic growth and voter behaviour. To this end the hierarchist institutions of society will anticipate and respond on the basis of scientific expert knowledge. The need for governance structures is emphasised. There is a preference for a risk-reducing control approach: decisions should be supported by the outcomes of cost minimisation, cost-benefit analysis etc. Technologies which can be planned and controlled are favoured and issues like oil dependence and public acceptance rank high[4]. Energy consumers can and should be guided towards 'rational energy use' – which is the justification for regulation, taxes,

4 In the context of ambitious government plans for nuclear power expansion in the USA and the former USSR, the phrase 'nuclear priesthood' was coined; in France some spoke of 'Les nucleocrates' (Simonnot, 1978).

information campaigns and the like. Hierarchist institutions will tend to suppress egalitarian and individualist counterforces unless they become a threat to their power, in which case they will be accommodated (e.g. the Greens, markets).

With regard to the previously introduced controversies, the hierarchist will make a prudent assessment of the potential for energy conservation and have an institutional bias towards large-scale supply-side options. Resource estimates will be rather conservative and there will be a cautious approach to the issue of climate change. Hierarchists will support cost-effective 'no-regrets' measures which reduce the risk of climate change, but are keenly aware of the fact that fast and stringent cutbacks in CO_2 emissions may be socially disruptive and create competitive disadvantages. Hence, a carbon tax should be 'realistic' and only be introduced if an internationally negotiated consensus is reached to avoid windfall profits or free riders (see, for example, Hourcade *et al.* (1995) on carbon tax evaluation). R&D programmes for new energy supply and efficiency options should get government support, because they too stimulate economic growth and (national) status.

The egalitarian perspective

The egalitarian wishes to reduce inequity and stresses the rights of those without a voice: our children, the poor, and nature. High and rising CO_2 emissions are seen as one more sign of humans' maltreatment of the Earth which may lead to catastrophes. Mathematical tools and models can play only a minor role because many of the issues at stake cannot be expressed in numbers or money. Egalitarians will advocate a morally founded justification for government regulation and support programmes. The more general issue of (under)development is seen as part of the problem; the claims of less industrialised regions that they should bear only a small part of the burden are supported. Egalitarians will be suspicious of large multinational (energy) companies whose concentration of money and knowledge makes them as much a part of the problem as of the solution. From an egalitarian perspective, science and technology can certainly solve part of the problem but add as much to it as long as their course is governed by centralised and commercial interests, and market ideology.

The egalitarian will embrace the 'precautionary principle' as a way to express his/her risk-averse attitude. Energy futures will be judged not only in terms of costs, but also with regard to distributive aspects and ecological impacts. A modest economic growth will probably be necessary but it should narrow the present income gap between the rich and the poor. Energy taxes are promoted as means to change wasteful production and consumption practices. Energy demand projections are much lower than official ones and have to be met to a large extent with non-fossil sources (Lovins, 1991). There will be a preference for decentralised and clean technologies, and therefore a natural tendency to focus on energy end-use needs and efficiency (Johansson *et al.*, 1989). Estimates of fossil fuel resources are on the low side, whereas the prospects of renewable energy sources are usually on the high side if compared with the hierarchist perspective. Development of renewable sources should be strongly supported by government RD&D programmes and indirectly by taxing carbon fuels because the market is often inadequate due to existing barriers and distortions.

The individualist perspective

For the individualist, entrepreneurial freedom and unhampered working of market forces gives the best guarantee for increasing material wealth and at the same time solving resource and environment problems. If energy-supply companies can operate in a regime of free trade and with a minimum of government regulation and interference, price signals will steer the transition away from fossil fuels before they are depleted. CO_2 emissions are probably increasing less than official expectations suggest – a view which may give rise to a somewhat odd coalition with egalitarians. The Earth itself is also far more resilient than we tend to think, so climate change impacts are probably exaggerated by those advocating strict measures. Moreover, there are several and relatively cheap options for adaptation (Nordhaus, 1991). The key resource is human ingenuity: human skills generate science and technology, which will bring options one cannot even imagine at the present (Simon, 1980). Not much can be said about the distant future in any case – what further opportunities and progress will, for instance, emanate from information technology, biotechnology, space technology? Technology is also the major driving force behind economic growth, which will ultimately benefit the poor.

The individualist emphasises the opportunities which arise from the search for new resources and new technologies to supply and conserve energy. Energy resources turn out, over and again, to be more abundant and cheaper than expected. Policy measures like a carbon tax are unnecessary. First, there are still too many uncertainties about the enhanced greenhouse effect and possible climate change to accept drastic measures. Secondly, they are ineffective because industries will move to other countries and consumers will stick to certain life-styles whatever the costs.

Of course, in the real-world actors rarely express their views in such a caricatural way. They are in constant interaction and often have strategic and public relations in mind as well. Moreover, positions may be implausible or even inconsistent when stakeholder share only part of the underlying values and judgements. For example, the egalitarian concerns about nuclear reactor safety and climate change have increasingly been incorporated in hierarchist policy formulation in the form of regulatory and negotiation frameworks. Similarly, the energy business community – part of which is rather hierarchist – is advocating the need for more efficient and environmentally friendly resource use options, at the same time emphasising the virtues of the market and the limitations of command-and-control approaches (Schmidheiny *et al.*, 1992). There is also the paradox that the egalitarian expectation of fast innovation in energy efficiency and non-carbon energy supply

Perspectives on energy

In their report 'Our Global Neighbourhood', the Commission on Global Governance warns that "the measures required to avert risks must be put in place immediately and those already in place – the Framework Convention on Climate Change... – must be rapidly and substantially strengthened" (Commission on Global Governance, 1995, pp. 83). Elsewhere they argue that "Energy efficiencies are an economic imperative for developing countries faced with capital expenditures to satisfy growing energy needs... And it is clearly in the interest of the industrial world to ensure that these countries have the financial and technological support required to meet these needs...A contribution could be made to alleviating the global warming problem through energy or carbon taxation..." (Commission on Global Governance, 1995, pp. 84, 212).

Many have argued that the situation requires drastic policy interference. In a report to Greenpeace the Stockholm Environment Institute puts the issue of life-style in the forefront (Lazarus, 1993): "Achieving a fossil free energy future will require major changes in energy policy and life-styles. The wasteful high energy consumption path that the North has enjoyed has to end. Future energy use will have to be extremely efficient, and increasingly based on sustainable renewable energy sources such as solar, wind and biofuels. The basis of that wasteful life-style is of course the economic growth and development path that we have chosen."

Or could it be that policy measures are more harmful than beneficial to resolve the climate change problem ? One of the two scenarios presented by Kassler (1994) of Shell Planning is called New Frontiers. It pictures a world of high economic growth in the less developed regions in which environmental problems are solved by market instruments. Renewable energy sources mitigate the threat of climate change: "As they progress along their learning curve, first capturing niche markets and then gradually expanding, new energy sources may well become commercially competitive over the next decades and start to be visible around 2020. [ ] Technologies will compete but the market will decide. [ ] With this perspective in mind, the idea of 'saving hydrocarbons for future generations' is perhaps unduly conservative. [ ] ... this scenario ... would have powerful implications for the climate change debate... There is an exciting challenge lying ahead: reaching New Frontiers following a path which makes economic sense. The industry has the capability ... Policy makers must also create the market conditions allowing this to happen." Not surprisingly, the mirror image of this scenario, called Barricades, is more dystopian: "liberalisation is resisted and restricted because people fear they might lose what they value most. [ ] There is increasing divergence between rich and poor economies...[ ] In the developed world, a number of non-governmental organisations... cause energy to be regarded as something bad and to be used sparingly, leading to an unfavourable investment climate in this sector".

Some assess other options as well: "A radical technological opton would be geoengineering, which involves large-scale engineering to offset the warming effect of greenhouse gases... The advantage of geoengineering over other policies is enormous, although this result assumes the existence of an economical and environmentally benign geoengineering option" (Nordhaus, 1994, pp. 80, 96). Or can nuclear energy rescue us? "...the growth in world population... and in human aspirations will likely generate a large demand for end-use energy over the next three hundred years... Only two options for expansion appear viable : coal and nuclear. [ ] If undesirable global warming... results from carbon dioxide generated by coal burning, a tolerable level of fossil fuel use can be established and the remainder made up by the nuclear option... [ ] None of the options for supplying the needed extra energy presents any important risk to life or health. " (Nathwani *et al.*, 1992, pp. 256, 259).

and imminent depletion of cheap oil and gas, is at odds with their fear that the high CO_2 emissions of the Business-as-Usual scenarios become reality (see e.g. Lenssen, 1996). Evidently, our implementation of the three perspectives into the energy model is only a first attempt to introduce real-world divergence in interests and values into a quantitative modelling framework.

13.4 Simulation results for the three utopias

In the previous section we introduced the three 'active perspectives' on world energy futures. The qualitative characterisations of perspectives and management styles have been translated into a set of assumptions and model routes. In Chapter 11 we gave a brief description of the integrated hierarchist utopia. Here, it will be discussed in some more detail, including a sensitivity analysis, followed by the egalitarian and individualist utopias. These are actually semi-utopias because only the driving forces (population and GWP) and the energy model assumptions are changed, while the water, land and cycles submodels are run according to the hierarchist utopia (see Chapter 11). The population/health utopian scenarios which provide inputs for the energy submodel experiments are described in Chapter 12.

Within the energy submodel a number of parameters has been chosen the same for all three perspectives. As to structural change (see Equation 5.1) we assume a further decline in average end-use energy intensity for the residential, services and other sector. For transport and electricity, however, it is assumed to keep growing in the next few decades. The lower limit on the AEEI-factor is set at 0.2 for heat and 0.4 for electricity. For another set of parameters we have made perspective-based assumptions, which are a reflection of the controversies and uncertainties outlined above. Some of these are related to expectations on energy intensity, and on end-use and conversion technology: the AEEI factor, the energy conservation cost curve and

Parameter	Hierarchist	Egalitarian	Individualist
AEEI ('technology')	average 1%/yr, all sectors	faster	faster
PIEEI ('prices')	moderate	cheaper and long payback times accepted	much cheaper and short payback times
TE (thermal electric) efficiency	rising to an average 50% in 2100	rising to an average 52% in 2100	rising to an average 60% in 2100
NTE (non-thermal electric) cost	moderate improvement	moderate improvement	fast learning, hence cheaper
coal cost	slow increase	removal of subsidies, hence fast increase	removal of subsidies and no learning in SF (Surface Coal), hence fast increase
gas resource base and cost	medium estimate	less, at higher cost	more, at lower cost
BLF/BGF (Bio Liquid/ Gaseous fuels) cost	moderate improvement	higher labour cost, more severe land constraint	lower labour cost less severe land constraint
carbon tax	no	towards \$ 500 per tC (\$12.5 per GJ) in 2020, constant thereafter	no

Table 13.1 Perspective-based model routes : indication of assumptions.

its rate of decline, thermal electric conversion efficiency and the learning coefficients for non-thermal electric power generation (NTE). As to energy efficiency, desired payback times for energy conservation measures and premium factors for coal have been varied. For NTE, the base load factor has also been differentiated. A second group has to do with the fossil fuel resource base and its exploitation: the long-term supply cost curves for coal, oil and gas, labour costs in underground mining and the learning coefficient for surface coal. A third group is related to biofuels (BLF/BGF): learning coefficients, labour and land costs, and the influence of land scarcity on biofuel yields. The management style is implemented on the basis of three policy variables: a carbon tax on secondary fuels, an RD&D programme for NTE and RD&D programmes for biofuels. The assumptions made for the present simulation experiments are based on a mixture of simulation experiments and literature estimates, and summarised in *Table 13.1* (see also Chapter 5 and de Vries and Van den Wijngaart (1995) and de Vries and Janssen (1996)). We have endeavoured to implement three quite divergent views on the energy system into a single model structure. However, such an attempt can only be partially successful as the model itself is also biased, for example, because of the importance given to relative prices in driving substitution processes.

Reference case: the hierarchist utopia

In the hierarchist scenario the AEEI factor is on average 1% per yr. Coal for electric power generation remains relatively cheap because governments support their coal industries for strategic and employment reasons. NTE options experience moderate learning of 10% decrease in specific investments for every doubling of cumulated production but cost reductions are counteracted by a declining base load factor due to storage and transport costs. The ultimately recoverable oil and gas resource base is rather large (72,000 and 60,000 EJ, respectively) but only 60% and 30%, respectively, are recoverable at cost levels less than 20 times the 1900 level. This reflects the rather conservative attitude of hierarchist resource estimates. The learning rate for surface coal is kept at a moderate 10%. Labour costs rise for underground coal but this is partly offset by a doubling of capital-labour ratios. Commercial biofuels are also assumed to have a 10% learning rate, which brings costs down to the level of \$ 10 to \$ 15 per GJ. Only for BLF is a modest R&D programme assumed; no carbon or energy taxes are applied. The assumptions are chosen in such a way that they reproduce important parts of the IPCC-IS92a scenario (Leggett *et al.*, 1992).

Use of secondary fuels and electricity increases from the present 220 EJ/yr to over 800 EJ/yr by 2100 (*Figure 13.1*). The largest growth is in electricity and the industrial sector. The share of electricity in final demand climbs from the present 19% to over 40% – a level which has almost been reached now for the US residential sector. About 40-45% of demand reduction between 1990 and 2100 is from autonomous improvements (AEEI). There is an additional reduction in the energy intensity of 3%

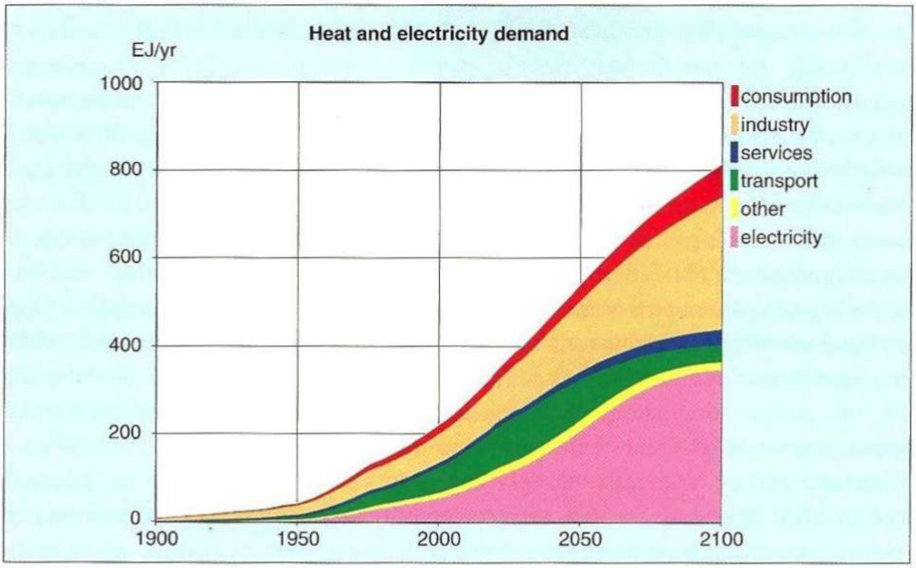


Figure 13.1 Sectoral non-electricity (heat) energy demand and electricity demand in the hierarchist scenario.

for electricity up to some 40% for the transport sector due to rising energy costs. By 2100 over 50% of the electricity is generated in non-thermal electric (NTE) power plants. Of the thermal electricity, 90% is generated by burning coal. The costs of coal-fired electricity rise, but penetration of NTE, stabilises the average electricity price. Coal production in the scenario increases almost fivefold to about 700 EJ/yr, near the level in the IPCC-IS92a scenario (*Figure 13.2*). The proportion of coal decreases until 2010 after which it starts rising; oil and gas will be depleted by the end of next century and biofuel-based substitutes have partly taken over (*Figure 13.3a*). In combination with medium economic and population growth, carbon emissions rise throughout the next century to over 20 GtC/yr by 2100 compared to about 6 GtC/yr in 1990 (*Figure 13.4*). Such an emission trajectory would lead to a CO_2 concentration using the hierarchist route for the CYCLES submodel of about 550 ppmv by 2100. This is considered 'acceptable' in view of expected risks.

Simulated price paths for coal, crude oil and natural gas are shown in *Figure 13.5*. Coal prices show a smooth and small increase, partly because surface-mined coal emerges as a cost-stabilising option which counteracts the rather steep increase in the cost of underground coal caused by depletion and rising labour costs[5]. The rise in oil and gas prices induces the penetration of biomass-derived fuels. Penetration of liquid biofuels (BLF) leads to a decline and later on, when land constraints become

5 It should be noted that coal liquefaction and gasification are not explicitly taken into account. In the IPCC-IS92a scenario, coal use is assumed to take place in the form of liquid and gaseous coal-based fuels.

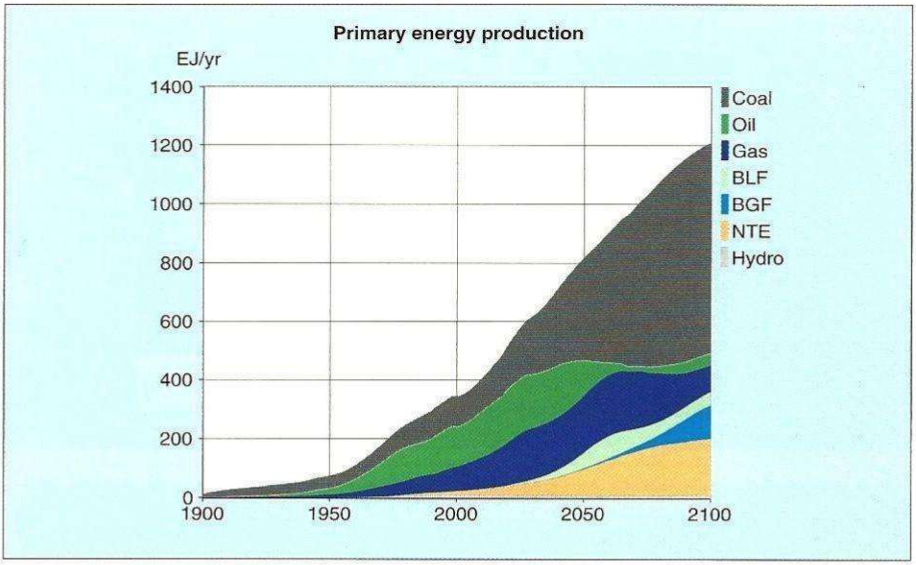


Figure 13.2 Primary energy production by fuel type in the hierarchist scenario.

more serious and learning ebbs away, a rise in the price of Light Liquid Fuel (LLF) at a level of about $ 15 per GJ or about $ 100 per barrel[6]. This price includes non-price barriers and in the present model formulation it is primarily an indication of the price differential needed to let commercial biofuels penetrate the market[7]. A similar pattern evolves for Gaseous Fuel (GF). The simulations suggest that biofuel technologies with the hierarchist characteristics would penetrate without the need for major demonstration projects. Of course, this hinges on the assumptions on the long-term supply – cost curves for conventional oil and natural gas and the biofuel production function.

Two important system characteristics are the over-all energy intensity and the average energy price. The latter gradually increases to about three times the 1990 level by 2100. Although energy use per capita doubles, there is a continuous decline in the energy intensity calculated as the ratio of primary fuel supply and GWP, from the present 14 to about 5 MJ/$. *Figure 13.6a* shows another system characteristic: the investments in the energy system. Almost half of these investments go into the electricity system, due to the capital-intensive nature of the NTE options. Because biofuel yields approach their limits, expensive oil re-enters the market and the investments in conventional oil exploitation remain significant in the second half of next century. Overall cumulative investments in the 1990-2020 period are in the

6 In the model biofuels only penetrate the markets for Light Liquid Fuel (gasoline, kerosene, etc.) and natural gas.

7 A better researched production function for biofuels and more insight into the substitution dynamics is needed to refine this analysis.

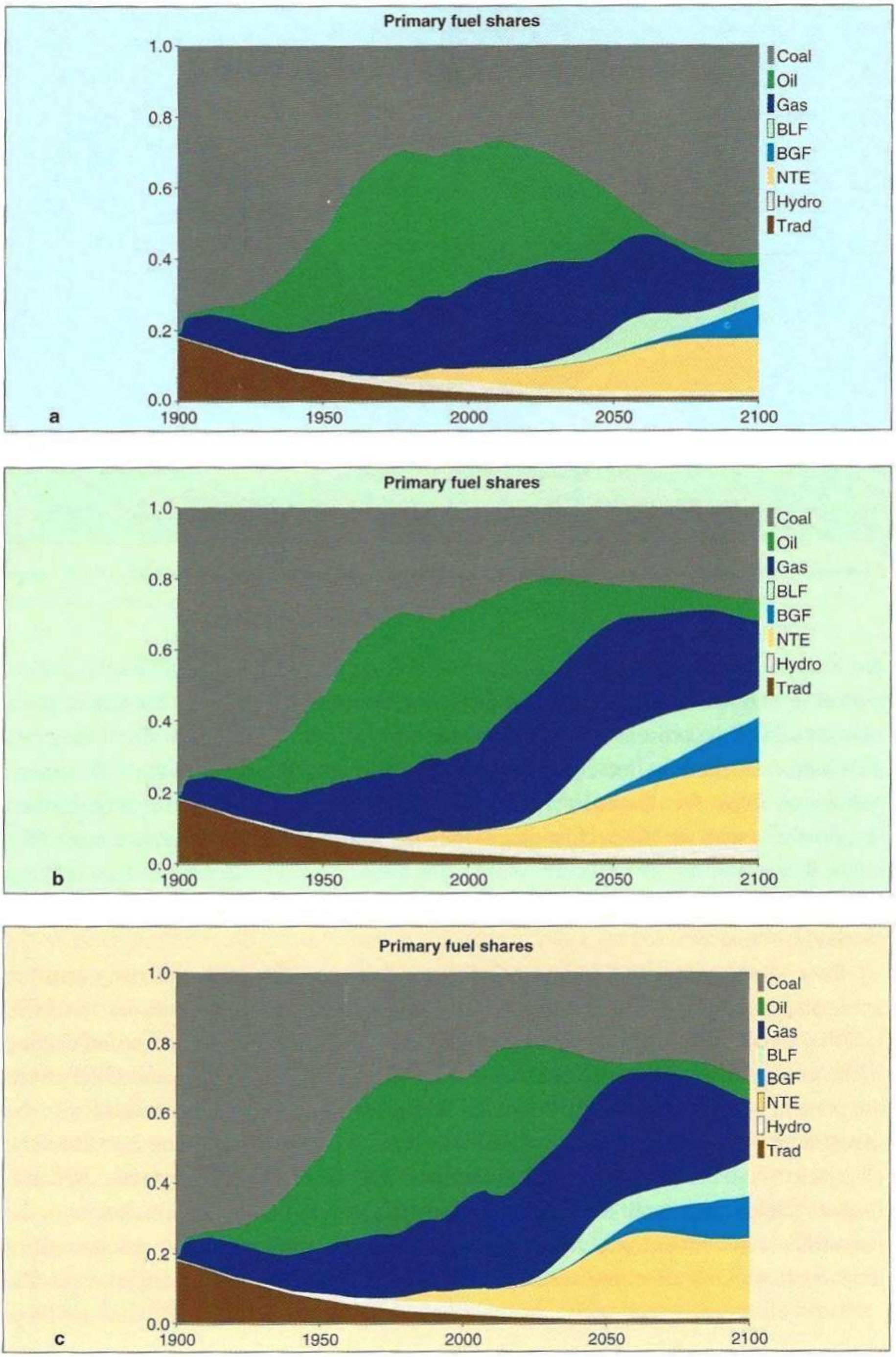


Figure 13.3 Proportion of fossil fuels and non-fossil fuel alternatives in the primary energy supply for the hierarchist (a), the egalitarian (b) and the individualist (c) utopia.

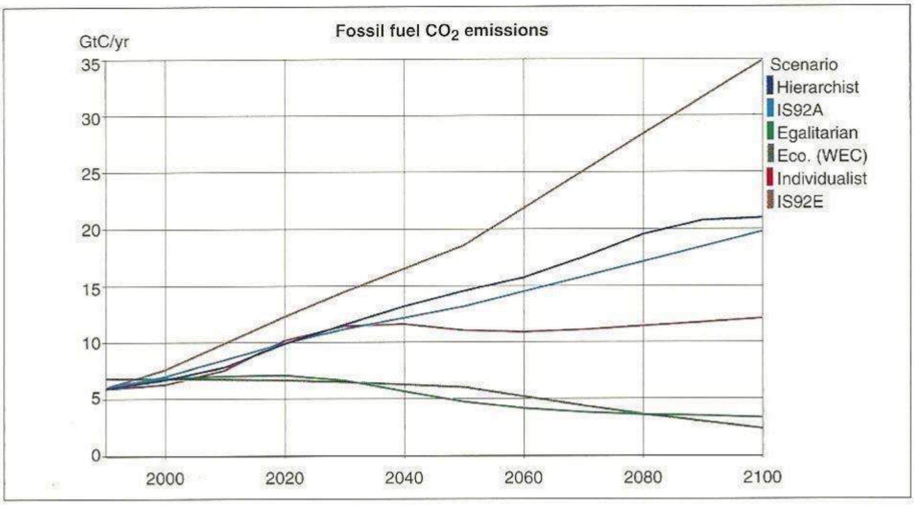


Figure 13.4 The CO_2 emission trajectories from fossil fuel burning in the three utopias for the period 1990-2100. Also indicated are three scenarios from other reports which can be associated with the three utopian perspectives. Note the difference between the individualist utopia and the high-growth IS92e scenario of the IPCC.

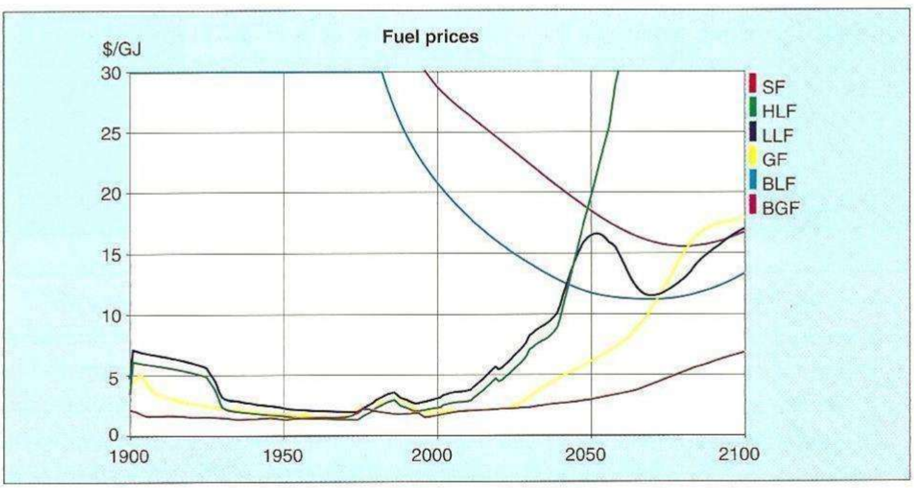


Figure 13.5 Changing prices of various fuels force fuel substitution into the hierarchist scenario. As fossil fuel resources are depleted, fuel costs rise but the rise in Light Liquid Fuel (LLF) and Gaseous Fuel (GF) costs are stabilised by the cost reductions in BioLiquidFuels (BLF) and BioGaseousFuels (BGF).

order of \$ 18×10^{12} (1990). This compares reasonably well with the recent estimates of cumulative capital requirements of \$ 16×10^{12} (1990) for a medium-growth scenario (IIASA/WEC, 1995). The overall energy expenditures, defined as the product of secondary fuel use and prices, rise as a percentage of GWP from about 6%

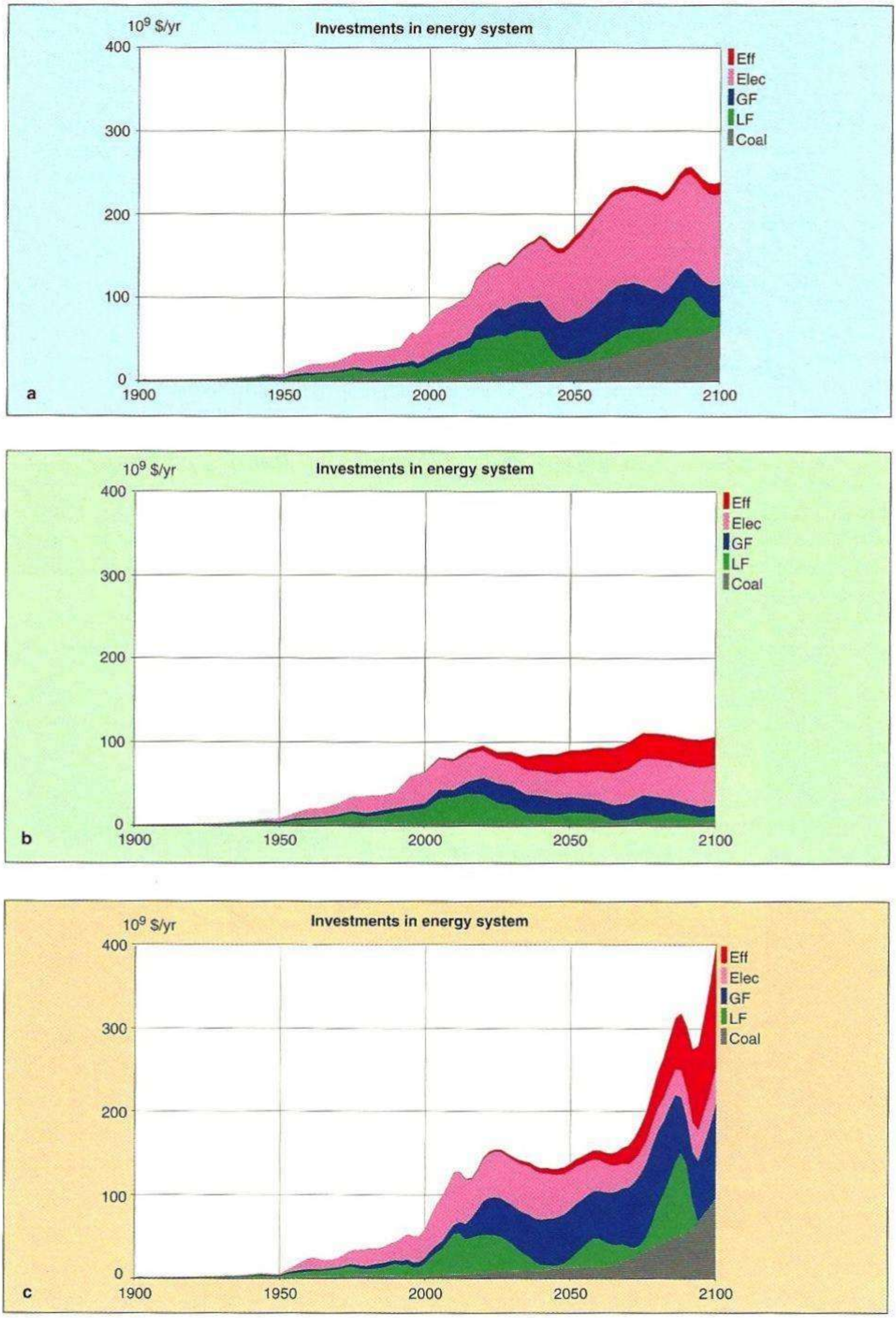


Figure 13.6 Energy system investments for the hierarchist (a), the egalitarian (b) and the individualist (c) utopia. Investments in enegy efficiency are underestimated because we assume replacements at no cost.

Sensitivity analysis

We performed a number of sensitivity experiments for the hierarchist scenario in which some key variables (energy demand, primary fuel production, CO_2 emission) have been calculated for a range of parameter values. The structural change parameter, i.e., the assumption on the relationship between sectoral activity and end-use energy demand (before AEEI and PIEEI, see Chapter 5) is kept constant for the three perspectives like another influential variable: the conversion efficiency from secondary fuel to end-use energy. Neither are included in the sensitivity analysis. The assumptions on the AEEI rate and the PIEEI cost curve induce changes in secondary fuel use in the order of about 15% for the domain of values found in the literature. A rather important assumption is the lower limit on the AEEI factor. The influence of the cost-curve decrease rate and the desired payback time only becomes pronounced (that is, more than ±10%) for values which are rather extreme, e.g. a 1% per yr decrease rate and payback times of more than eight years

Electricity use only drops significantly if more optimistic assumptions are used for the AEEI factor and the price elasticity. We also explored what would happen if the structural change parameter for electricity demand remains at the present high level and is reduced by half for non-electricity demand – a transition to an 'all-electric' society. The share of electricity in final demand rises from 19% in 1990 to 51% instead of 42% in 2100. The resulting CO_2 emissions in 2100 are reduced by 2.3 GtC/yr as compared with the reference case, giving an indication of what successful introduction of electric cars, for example, could mean.

On the supply side, the assumption that thermal electric conversion efficiency rises to 70% in 2100 instead of 45% causes a 30% reduction in fossil fuel use for electric power generation. However, equally large reductions occur, at least in the long term, when the NTE learning coefficient is doubled and/or NTE can be operated at a high (0.8) base load factor. Another sensitive parameter is the low cost of coal for electricity generation: a doubling can be expected to induce a major shift towards oil and gas which in turn will stimulate the introduction of biofuels. For the cost assumptions on coal, oil and gas, it is the shape of the long-term supply cost curve determining the oil and gas depletion cycle and hence fuel substitution dynamics, which really matters. The results of these sensitivity analyses have been used in the implementation of the perspective-based model routes.

at present to 10% for the second half of next century, which is comparable to the high level in the 1980s (*Figure 13.7*). The slow rise in the next 40 years reflects the increasing costs to produce oil.

These simulation results describe a medium-growth world in which the energy transition is only partly realised. Energy intensity decline is impressive; biofuels and non-thermal electricity generation do play a role, but abundant resources bring coal back to the forefront in the second half of the next century, when oil and gas resources become uncompetitive. This, and one of its consequences, rising CO_2 emissions, is one of the more controversial aspects of this scenario.

The egalitarian utopia

If the world is managed by egalitarians, there will be more incentive to develop energy efficiency-oriented technology and stimulate its penetration[8]. We assume that with active support from the NGOs the AEEI rate can be raised to 1.5% per yr and

8 We have not changed the structural change multiplier, as such changes would require more research. There are good arguments for an egalitarian world to have a lower growth elasticity because of changing life-styles, more public transport and the like. On the other hand, the lower GWP growth rate slows down in the model, at a rate at which structural change contributes to a lower energy intensity.

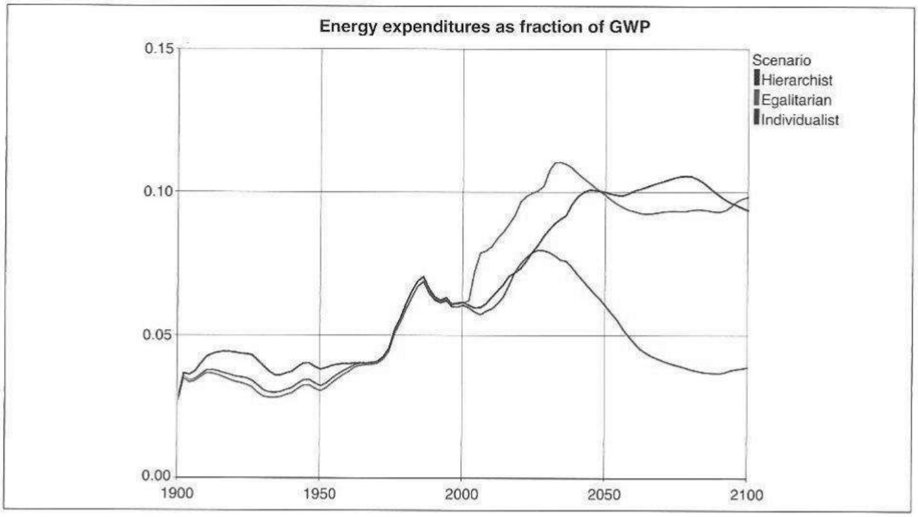


Figure 13.7 Expenditures on energy as a fraction of GWP for the three utopias. Expenditures are calculated as the product of secondary fuel and electricity use and their respective prices, excluding a carbon tax.

that the decline in the PIEEI cost curve is twice as fast as in the hierarchist scenario. Moreover, consumers are willing to use longer payback times because of information campaigns and concern about impending climate change. It is also assumed that coal use is actively discouraged in both the end-use and the electricity generation market due to its environmental disadvantages. The major policy instrument is a worldwide carbon tax increasing to \$ 500 per tC (about \$ 12,5 per GJ) in 2020 and constant thereafter. This would be accepted after successful negotiations during which regions like China and India are convinced to revise their coal expansion plans and to focus instead on oil and gas, the availability of which increases because of energy conservation efforts in the industrialised regions. Later on, their economies will be strong enough to introduce the renewables, by then significantly cheaper.

In the egalitarian utopia the population is only 8×10^9 at \$ 7000 per cap in 2100 (see *Figure 12.2b*). Mainly as a result of this and the carbon tax, the trajectory of secondary fuel use is almost 70% below the hierarchist scenario. The proportion of electricity grows towards 50%. The AEEI factor runs about 10% point below the hierarchist scenario values. The price-induced energy conservation increases to 35% (services) – 55% (transport) by 2100 as compared to 5-10% in 1990; for electricity it is still a low 5%. Electricity generation in an egalitarian utopia will use less coal because it is more costly. Moreover, efficient combined-cycle and fuel-cell power plants lead to a higher average thermal electric conversion efficiency and NTE options are vigorously supported. As a result, fossil fuel use is down by a factor of almost 4 compared to the hierarchist utopia. There are some 18,000 large power plants less than in the hierarchist scenario.

With regard to fossil fuel supply, the more conservative estimate of low-cost natural gas availability – also reflecting the attitude that such valuable non-renewable resources should be saved for future generations – allows for an earlier and faster penetration of modern biomass-based fuels. The result is that primary fuel production peaks at 400 EJ/yr in 2025 and coal production remains at the 1990 level, while its proportion drops to 20-25%. Renewable sources increase their contribution to almost 50% by 2100 (*Figure 13.3b*). This is reflected in CO_2 emissions peaking at about 7 GtC/yr between 2000 and 2030, after which they decline to 3-4 GtC/yr (*Figure 13.4*). The carbon tax discourages the use of fossil fuels and especially coal: its price increases fourfold between 2000 and 2020. Investments flow into energy efficiency and non-fossil fuel-based electricity generation to the extent that in the second half of next century over two-thirds of total investments go to these two options[9]. The absolute investment level is modest, at most twice the present one (*Figure 13.6b*), but as a fraction of GWP, it rises to 10% around 2040 after which it slowly declines to about 8% (*Figure 13.7*). In the egalitarian utopia the present generation indeed makes a sacrifice for the next, but whether and how much this will benefit these future generations is the question. It will be discussed in Chapter 17 and 18.

The individualist utopia

For the individualist, a utopian world will be driven by markets and prices, and technological innovation. The differentiation with regard to the other perspectives has been introduced by higher rates of energy efficiency improvements and fast learning for non-fossil supply options once the prices signal their competitiveness. The consumer will tend to use a short-term horizon, hence short desired payback times. Like the egalitarian, the individualist supposes that the price of coal will go up because it is inconvenient and subsidies are removed (Kassler, 1994; IIASA/WEC, 1995). For surface-coal mining environmental impacts absorb the cost reductions from learning. The assessment of natural gas resources is optimistic: the same amount as for the hierarchist is available at half the cost. Options for high-efficiency thermal conversion will fulfill their promise: by 2100 thermal efficiency reaches an average 60%. NTE capacity can be operated at a high base-load factor. Biofuels become cheap because of fast learning and cheap labour.

All this technological optimism leads to an individualist utopia in which energy use does not exceed the hierarchist level of about 800 EJ/yr by 2100, 40% of which is in the form of electricity. This is possible with the high economic growth rate because the energy intensity declines to a very low 2.5 MJ/$ due to 50-70% autonomous efficiency improvements and 20-30% price-induced efficiency improvements with respect to 1990. NTE rapidly penetrates the electricity generation

9 Without the - high - carbon tax, CO_2 emissions are about 5.4 GtC/yr by 2100. The investments in energy efficiency are underestimated because we do not consider replacement costs.

market up to 50% by 2050 and 80% by 2100. Biofuels grow to a rather small 10% by 2050 as they have to compete with cheap natural gas. However, by 2100 they contribute in the order of 25%, when both oil and gas have become scarce and expensive (see *Figure 13.3c*). Coal use increases to some 250 EJ/yr by 2100 as compared to over 700 EJ/yr in the hierarchist scenario. These changes together lead to a stabilisation of CO_2 emissions at 10-12 GtC/yr from 2030 onwards (*Figure 13.4*). The investments in the energy system rise steeply after 2030, when fossil fuel depletion starts to play a role (*Figure 13.6c*). As a fraction of GWP, they are of the same order of magnitude as in the egalitarian utopia (*Figure 13.7*). This reflects the technological optimism of the individualist borne out in the form of cheap and abundant non-fossil fuel options to supply energy for a huge economy with highly efficient energy consumers. Prices of oil-based fuels increase and are successfully stabilised by cheap biofuels, but after 2060 biofuels start to face land-related constraints and prices go up. Coal prices go up only slightly faster than in the hierarchist scenario because the slower depletion rate partly compensates the cost increasing factors.

13.5 Uncertainties and dystopias: some more model experiments

The implementation of the three perspectives gives an indication of the uncertainties which surround any projection of energy-related variables. In this section we present an uncertainty analysis in which for a given population-economy scenario and energy perspective, input variables and parameters are varied across the uncertainty domain generated by the implementation of the three perspectives. Next, we discuss futures in which the dominant management style within the energy system is at odds with how the world really is. There are 24 such semi-dystopias (see Chapters 10 and 11). We choose to highlight only a few of them, on the basis of the plausibility and consistency of the related stories.

Uncertainty ranges for the three utopias

We performed an UNCSAM analysis to assess the uncertainty involved in the various scenarios. For each of the three utopias, all the input parameters and variables used for the differentiation of the three perspectives are varied uniformly throughout the domains. The population and GWP scenarios are given their utopian values and are not varied. *Table 13.2* shows the 2.5 and 97.5 percentile values for a few key output variables: the values for the utopias are given in parentheses. *Figure 13.8* presents the CO_2 emissions that correspond with these experiments.

For the hierarchist world 95% of the paths of secondary fuel and electricity use in 2100 fall between 610 and 790 EJ/yr. The uncertainty on primary energy supply is slightly greater; CO_2 emissions in 2100 vary between 11.5 and 17 GtC/yr. Major parameters and variables which contribute to the uncertainty band are: the AEEI and its lower limit for industry and electricity, the relative cost of labour in underground coal mining, the learning coefficient for NTE and biofuels, and the thermal efficiency of fossil-fired power plants. The rather narrow uncertainty band is partly due to the fact that the relationship between end-use energy demand and activity levels is the same for all three perspectives. The divergence in the assumptions on NTE options and biofuels is reflected in the factor 2 between the upper ($ 20 per GJ) and the lower ($ 9.5 per GJ) probability paths for the average energy price by 2100. This creates a rather large difference in the incentive for energy conservation but the final impact is relatively minor due to the effect of the assumed rise of the marginal cost of energy conservation. Also, a number of uncertainties may cancel each other out.

In the egalitarian utopia, uncertainty bands for energy demand and CO_2 emissions are in relative terms similar to the ones in the hierarchist world, but are quite small in absolute terms, despite a rather large uncertainty in the average energy price ($ 8.5 - $ 16 per GJ by 2100). This indicates that the assumptions on population and economic growth dominate. In the individualist utopia, the average energy price in the coming decades is much below the uncertainty bands for the hierarchist and the egalitarian. However, after 2025 it starts to exceed the hierarchist and after 2055 the egalitarian value spectrum. By then the resource constraints become more severe because cumulated production is the highest of all three utopias. From a resource-depletion point of view, the individualist world view indeed favours the short-term benefits. For energy demand and CO_2 emissions the relative

Variable value in 2100	**Hierarchist**		**Egalitarian**		**Individualist**	
	<2.5%	>97.5%	<2.5%	>97.5%	<2.5%	>97.5%
Secondary energy use (EJ/yr)	610	790	190	220	980	1220
	(810)		(250)		(800)	
Primary energy production (EJ/yr)	830	1110	270	330	1280	1630
	(1230)		(300)		(1070)	
CO_2 emission (GtC/yr)	11.5[a]	17[a]	2.5[b]	3.6[b]	14.5	21.5
	(20)		(3-4)		(12)	
Average energy price ($/GJ)	9.5	20	8.5[c]	16[c]	13	24
	(16)		(15)		(11)	

[a] Peaking in 2080 at 13 GtC/yr and 18 GtC/yr, respectively.
[b] Peaking in 2000 at 6.5 GtC/yr and in 2025 at 7.6 GtC/yr.
[c] Peaking around 2040-2060 at $ 13.5 per GJ and $ 18 per GJ, respectively.

Table 13.2 Uncertainty ranges for the three utopias (utopia values in parentheses).

uncertainties are comparable with those in the other two utopias. In absolute terms they are large, 14.5-21.5 GtC/yr for the period 2080-2100, which emphasises the risk aspect of such a future if the climate turns out to be sensitive.

It is interesting to analyse the position of the utopian values relative to the uncertainty ranges. It turns out that the hierarchist projection of energy use and CO_2 emissions in the utopia is outside its uncertainty bands (see *Table 13.1* and *Figure 13.8*). The reason is that the technological optimism of both the egalitarian and the individualist world view weigh heavily, and making the hierarchist estimates implausibly high, given its medium population and economic growth projection. For the same reason, energy use and CO_2 emissions in the egalitarian utopia fall above or at the upper end of the uncertainty range. For the individualist utopia the opposite happens. The rather conservative estimate of size and cost of oil and gas resources and the diverging views on coal prices in the hierarchist and egalitarian scenario pull the individualist utopia down to the extreme low end of its uncertainty range. In 2100, for instance, utopian CO_2 emissions are between 2050 and 2100 10-12 GtC/yr, whereas 97.5% of all uncertainty experiments show an emission path above 13 GtC /yr, indicating that the estimate of CO_2 emissions in the individualist utopia have a fair chance of being exceeded.

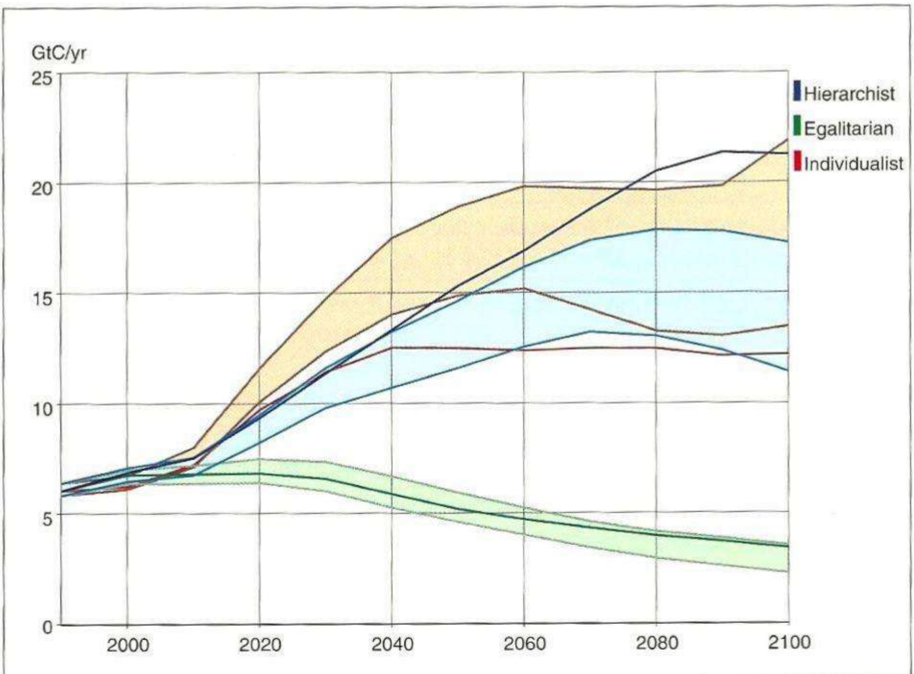


Figure 13.8 The uncertainty ranges in the CO_2 emission paths for the three scenarios for the period 1990-2100. The shaded areas indicate the 95% percentile for the three utopias.

Dystopian futures

Non-utopian futures are, in the present context, scenarios in which the world view and/or management style with regard to the energy system differ from those applied for population/health and economy. Although such discordance does not always have disruptive consequences, we will refer to such scenarios as dystopias (see Chapters 10 and 11). We confine the discussion here to two variables. *Figure 13.9* shows the energy expenditures along the *y*-axis as a fraction of GWP in 2100 and the CO_2 emissions in 2100 along the *x*-axis. Energy expenditures, defined as the product of secondary fuel and electricity use and their respective prices but excluding any carbon tax, are used as a proxy for the economic cost. The triangles within the solid lines are drawn around the three points with the population-economy perspective, i.e. the 'background', individualist (I) and egalitarian (E). The experiments with a hierarchist background give results in-between.

With the hierarchist or egalitarian world view on the energy system, the high-growth individualist background would raise emissions far above the IPCC-IS92a level of 20 GtC/yr (upper points in triangle I: HII, HHI, EII, EHI[10]). This would be disastrous in a world with a sensitive climate system (see Chapter 16). The technological optimism of the individualist would more than halve these emissions at substantially lower relative expenditures (lower points in triangle I: III, IHI). The dashed triangle (I*) shows how the situation changes with an egalitarian management style, i.e. with a $ 500 per tC carbon tax: relative expenditures rise by more than 2% of GWP and emissions are 40-55% lower for the hierarchist and egalitarian world view (upper points in triangle I*: HEI, EEI). With an individualist view on the energy system, the carbon tax is equally as effective in reducing CO_2 emissions as an egalitarian view.

The low-growth egalitarian background would imply emissions in 2100 below 8 GtC/yr, irrespective of the way in which the energy system is seen. However, costs differ significantly: with a hierarchist or egalitarian world view, energy expenditures as a fraction of GWP are 2-3 times higher (upper points in triangle E: HEE, EEE). The individualist assumptions on technology roughly halve emissions to less than 4 GtC/yr (lower point in triangle E: IEE). If in this situation a carbon tax is applied, emissions are reduced even further but at very high relative costs for a hierarchist or an egalitarian view on the energy system (upper points in dashed triangle E*: HEE, EEE). Even if the individualist technological and resource optimism were only partly justified, a carbon tax in a world with a low population and economic growth of the egalitarian utopia would be an unnecessary and expensive venture.

Of course, management styles which are obviously in disagreement with real-world observations will not be maintained for a whole century (see Janssen, 1996).

10 The index WMB means world view W, management style M and background B. Note that the points HII and HHI coincide because the management style of the hierarchist and the individualist hardly differ.

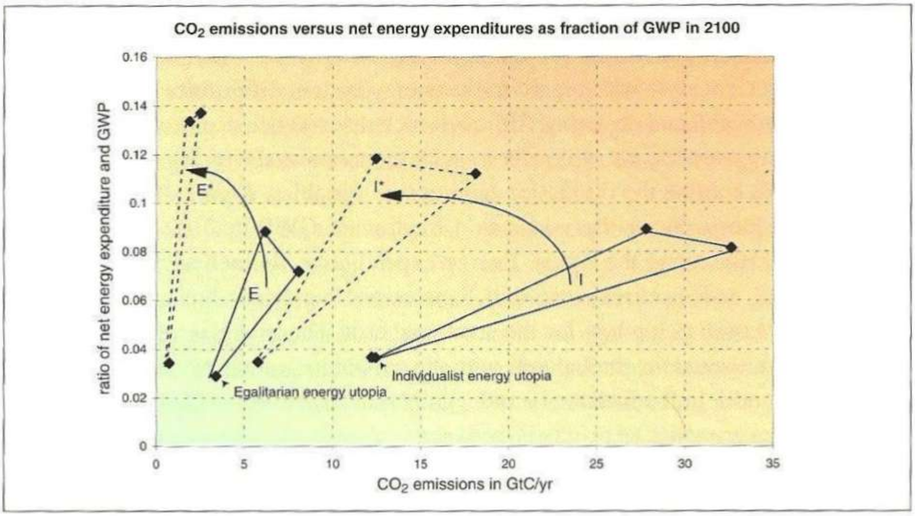


Figure 13.9 CO_2 emissions versus net energy expenditures as a fraction of GWP in the year 2100: the egalitarian and individualist utopias and dystopias, and the consequences of an egalitarian management style ($E \rightarrow E^*$; $I \rightarrow I^*$). Assessment of risks associated with high CO_2 emissions are given in Chapter 16.

No human response to dystopian tendencies is modelled. Another shortcoming is that the introduction of a carbon tax is not supposed to influence the economic growth scenario. If such a tax were to slow down economic growth, its (non-) implementation could have much larger, though not necessarily more dystopian repercussions. Yet, it is clear from these simulation experiments that the aspiration of a high-growth world has to rely on a combination of technological optimism and

Dystopian narratives

One possible dystopia is indicated by the upper right points in triangle I (Figure 13.9). High economic growth is successfully pursued and the consumer society is too seductive for most world citizens to resist. The expected decline in energy intensity and decarbonisation does not take place. Energy conservation and renewable energy turn out to be expensive. Vested interests ranging from reluctant oil-exporting countries to China and India opposing any curtailment of their coal expansion plans obstruct the implementation of regulatory policies. Attempts to introduce an egalitarian management style are confronted with bureaucratic opposition and system inertia. In such a high-growth world (individualist) with disappointing results from technology and emission-reduction policies, CO_2 emissions would soar to the high levels feared for by some egalitarian groups.

The upper part of the dashed-line triangle, E*, is a different story. If public opinion is swayed towards an egalitarian management style in a low-growth future, emissions will drop because of stringent emission reduction policies. If the climate system then turns out to be insensitive, an unnecessarily large burden has been placed upon the economy – most of which, however, cannot be explicitly modelled[11]. The large energy expenditures may aggravate poverty and inequity, and add to social unrest.

11 Here the feedback parameter for economic growth can be experimented with.

energy taxing if the world wants to avoid emissions exceeding the 10 GtC/yr level. Also, if the emissions of 5-10 GtC/yr or an equivalent 500-1000 GtC cumulative emissions during the next century are considered an acceptable range, the imposition of a high carbon tax would be a heavy and unnecessary burden in a low-growth world.

13.6 Conclusions

We have used the Energy submodel TIME to investigate possible energy futures. Implementing divergent estimates of important model parameters and performing experiments with the resulting perspective-based model routes produces a wide spectrum of energy futures. The hierarchist utopia closely resembles the IPCC IS92a scenario which is often used as a yardstick in climate policy research. The egalitarian utopia resembles several published scenarios, as does the individualist utopia. There may be important differences, for example, due to the omission of model experiments which account for coal liquefaction and gasification or an 'all-electric' or hydrogen-based energy economy. Nevertheless, we feel confident that the three utopian scenarios form good basis for the integrated TARGETS1.0 simulations discussed in subsequent chapters.

The uncertainty analysis performed with the Energy submodel confirms the view that the IPCC IS92a scenario – which is similar to the hierarchist and can best be called a coal scenario – is rather implausible. For the chosen population and GWP scenarios an integrated approach such as that used in the Energy submodel indicates a CO_2 emission range of 2.5-21.5 GtC/yr by the end of next century. Both the hierarchist and the individualist utopia imply rather high environmental risks. The egalitarian utopia poses a much smaller threat to the environment, but it may jeopardize the material welfare of large groups of people. It seems both utopias have a rather low probability of occurrence because of the many counterbalancing forces wthin the system.

Most probably the next decades will see the effects of all three utopias. In different ways, they will all contribute to a transition away from an energy-inefficient and carbon-based energy economy. But only events which can neither be anticipated nor modelled at present can bring global CO_2 emissions below 1990 levels within 30-40 years. Some fear a sudden change in climate across large parts of the world or a severe disruption in oil trade. Others look forward to such events as the discovery of a huge new gas province or a technological breakthrough in the ways in which we use and produce heat and power. Such differences in perspective will always colour the outlooks on the future. This chapter provides answers to some of the questions posed in section 13.1; the rest are in Chapter 16.