Future Images for 2050
Energy

Climate OptiOns for the Long term

COOL Europe

Input paper for the 2nd COOL Europe workshop, 6-7 april 2000, Brussels

Based on input from the participants in the sector dialogue groups transport and energy, workshop 1, 29 November 1999

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INTRODUCTION

During the first workshop within the COOL Europe project, a brainstorm session was held in which the participants discussed possible future developments for the energy sector and the transport sector in Europe up to the year 2050. This document, which serves as input for the second workshop, describes a possible future image for the energy sector. The image is based on the input of the participants during the first workshop. In a separate document the future image for the transport sector is described.

The two images follow the same structure: each image contains four categories: (1)fuel switch, (2) energy efficiency, (3) structure and patterns and (4) awareness, behaviour and lifestyle.

In the first section of this paper the general assumptions underlying the two images are described. The second session contains the Energy Image for 2050. In Appendix I, more background information is provided.

1. GENERAL ASSUMPTIONS

1.1 Introduction

In this section we will describe the general assumptions underlying the COOL transport and energy future images. We briefly describe the drivers that determine energy consumption. We also present an overview of the energy supply & demand system, which can be helpful in determining the competition between various energy demands and in checking the consistency between the various images.

1.2 The energy supply and demand system

Figure 1 shows an overview of the economy, divided in its subsectors, industry, buildings (including both residential and commercial/tertiary sector buildings), transport and agriculture. For each subsector a number of important drivers are listed. Section B.1.1 of the background paper for the energy image provides a short description of the drivers and how they influence energy consumption.

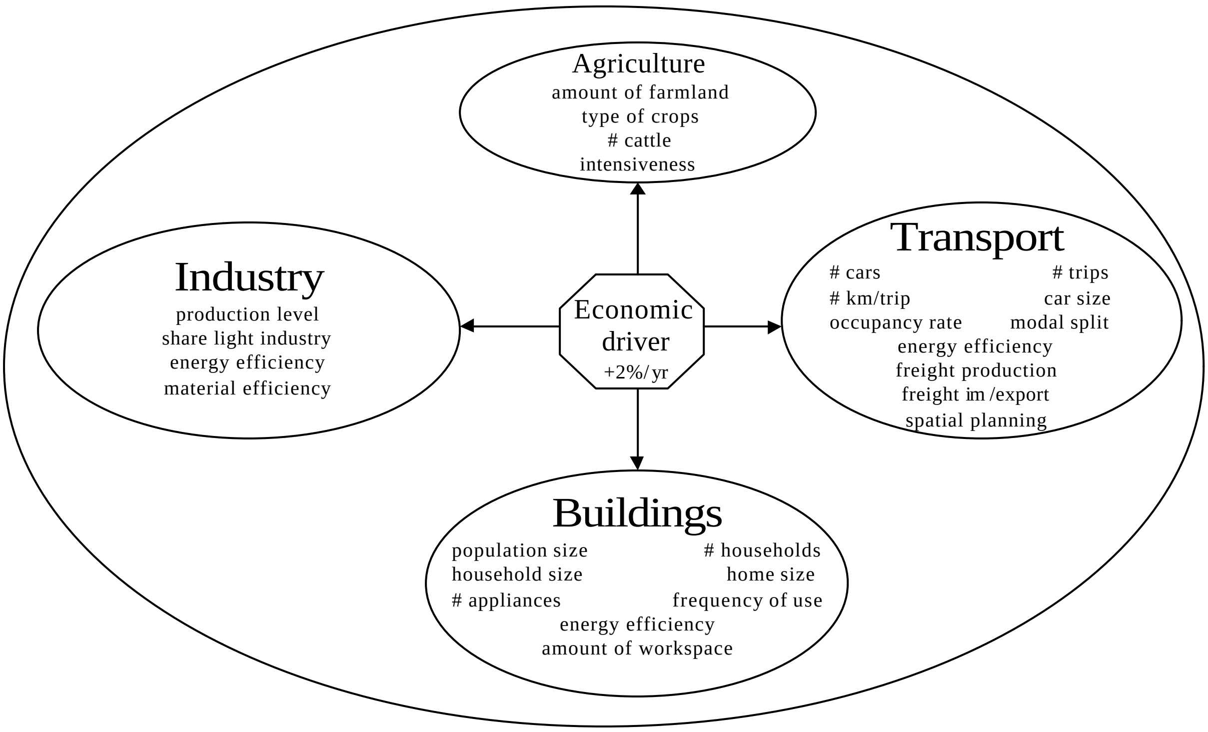


Figure 1: A schematic representation of the economy by sector and important drivers of energy consumption.

Within the energy supply system various sources (e.g. wind, biomass, coal) basically deliver a limited number of energy functions or energy carriers. In Figure 2 we distinguish electricity, heat (low temperature, high temperature and steam) and fuels. With fuels we mean the use of fuels for other purposes than providing heat or steam, such as automotive power. Not all sources can be used to provide all carriers. Nuclear power, wind power and hydropower only deliver electricity. CHP (Combined Heat and Power generation), solar energy and biomass can deliver both electricity and heat. On top of that biomass can also provide fuels. Natural gas, oil and coal can provide all three carriers (in Figure 2 coal is not included and oil is only used to produce fuels as we envision their use to be limited in our future energy image). Of course the electricity from electricity-only sources can subsequently be used to produce fuels through electrolyses (hydrogen out of water). This option is currently not included in our image, but might be used to limit fluctuations in supply or in case more electricity can be generated from renewable sources than required. It must be noted that there can be competition between different energy demands. For example, if a large amount of biomass is used for bio-fuel production there is only a limited potential for biomass-based electricity generation. Therefore, the choices made in the two images are interdependent.

Basic assumptions in our future images:

- Total energy consumption will stabilise at current levels. This is the result of a 2%/yr growth in activity, a 1.5%/yr energy efficiency improvement and a 0.5%/yr structural change. Structural change will be realised by shifts towards less energy-intensive products, and a higher contribution of energy-extensive sectors such as information technology, services, etc. to GDP.
- In accordance with the preferences of the participants of the first workshop the energy supply system will become more decentralised. This means electricity will be generated by decentralised systems, such as solar, (on-shore) wind and CHP (Combined Generation of Heat and Power. Besides CHP, heat will also be supplied by heat pumps. It must be noted that a decentralised supply system, with largely small-scale generation capacity limits the potential for CO2 removal and disposal.
- To achieve both the stabilisation in energy consumption and the shift in energy carriers and conversion processes consumers need to be ‘environmentally aware’ and actively stimulate the supply of energy and carbon-extensive options by creating a demand for these options.

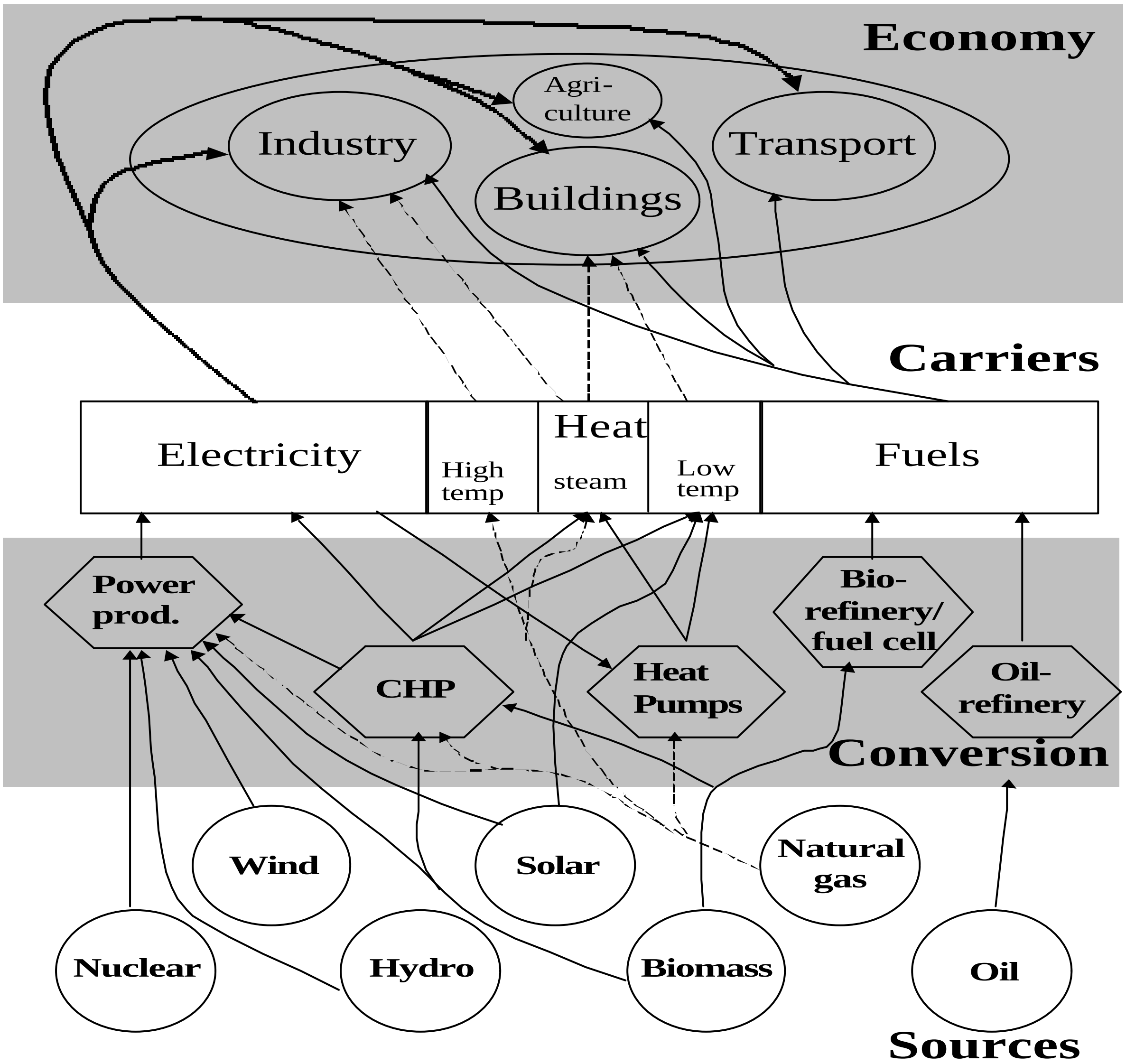


Figure 2: The future image of the energy supply and demand system in 2050.

1.3 Categorisation of energy savings and emission reduction options

Energy savings options and emission reduction options can be categorised in many different ways. In this paper we have chosen a distinction in energy savings and emission reductions resulting from:

- Fuel switch
- Energy efficiency
- Structure and patterns
- Awareness, values and lifestyles

Here we will discuss how Figure 2 is connected to these four categories.

- Fuel switch
  Decisions on fuel switching are made in the conversion sector (the bottom half of Figure 2) on the basis of the expected demand for fuels, electricity and heat, the expected prices

and considerations regarding the security of supply, regulations, resource availability (i.e. land), import dependency, PR, etc. Of course the consumer can influence this decision-making by demanding certain types of energy (e.g. green electricity, see also bullet 4). In a more decentralised future these decisions will to a larger extent be made by the end-user (PV panels or solar boilers on homes, CHP in industry).

- Energy efficiency
  Energy efficiency improvement can take place both on the supply side and on the demand side. The current energy efficiency of conversion processes, such as electricity plants, CHP plants, heat pumps and refineries can be improved, thereby reducing the amount of primary energy carriers required to fulfil final energy demand. Within the economy the efficiency of industrial processes, cars, farm vehicles, houses and offices (in terms of insulation, orientation etc), appliances, etc. can be improved.
- Structure and patterns
  A shift in structure and patterns can result in either an increase or a decrease in energy consumption. Shifts that reduce energy consumption can, for instance, be an increased railroad capacity (for passenger or freight transport), a shift towards less energy-intensive products (e.g. from aluminium soda cans to glass or plastic bottles), towards more recycling, towards a more service-oriented economy or a shift away from intensive farming. Also spatial planning can influence energy consumption, i.e. large malls on the outskirts of town vs. local shops.
- Awareness, values and lifestyles
  Behaviour and awareness can strongly influence energy consumption, but is relatively difficult to quantify. In order to realise the full potential of emission reductions that can be obtained through fuel switch, energy efficiency improvement and a shift in structure & patterns a change in behaviour and awareness is required. This holds for car drivers (are they willing to carpool, to switch to public transport, or to move closer to their work?), for buyers of appliances (are they willing to pay a higher initial price for reduced operation costs?), for electricity consumers (are they willing to pay extra for green electricity?). for manufacturers (are they willing to accept higher pay-back periods on their energy efficiency investments), etc. Also the awareness of policy makers plays a role: Are they willing to use policy instruments such as carbon taxes and regulation? Values of ‘the society’ as a whole are of influence: Do we accept a higher energy import dependency? How do we value biodiversity (monocultures in biomass production)?

1.4 Consistency between the images

It must be noted that the Transport image is currently not consistent with the Energy image (e.g. in terms of assumptions on inputs of natural gas, biomass, electricity and solar-based fuels).

2. ENERGY IMAGE FOR 2050

2.1 Introduction: an overveiw of the energy system in 2050

In this section we will present the energy image. We will give a summary of the basic assumptions, results and the consequences of the choices made. More detailed background information can be found in Appendix I.

Basic assumptions:

- Stabilisation of total energy consumption will occur in 2050 at current levels;
- The energy supply system will be largely decentralised;
- No coal consumption is envisioned;
- Biomass will mostly be used for fuels (except for aviation fuels);
- Electricity will largely be supplied by Combined Heat and Power generation;
- Low temperature heat will be supplied by heat pumps;

Consequences of the energy image:

- Large renewable input can result in a reduced security of supply, unless storage capacity can be developed.
- Biomass consumption requires 80 Mha land (or 17% of total land area in Europe, the estimated long term excess crop land in Europe is estimated at 65 Mha).
- Loss of biodiversity could result from monoculture biomass plantations.
- It is unclear whether water availability is a limiting factor.
- PV electricity production requires PV panels to be installed on 35 million houses (roughly one sixth of total number of houses) with a panel size of 20 m^2.
- An increasing import dependency for gas might become an issue.

The energy image is constructed on the basis of the potentials for the various sources, the estimated requirements for each type of carriers and the relative growth paths for the different sectors. For more details see the background document.

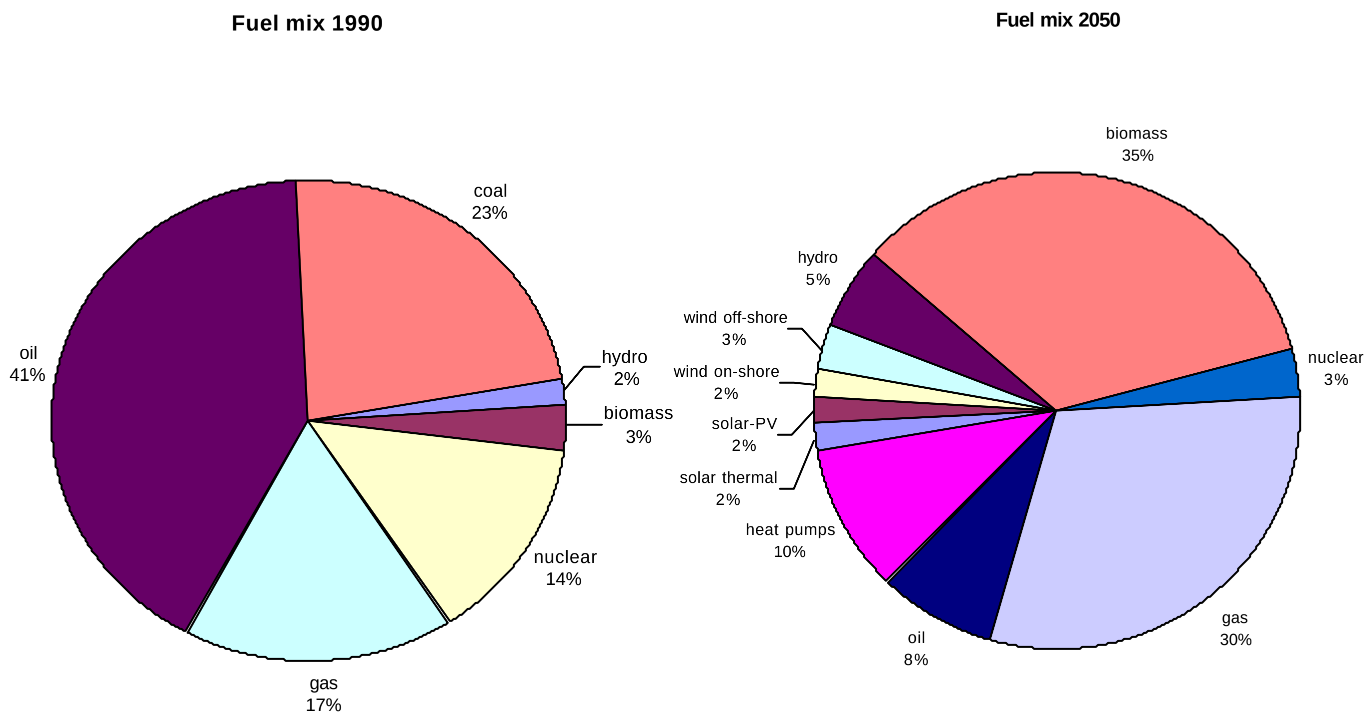
It must be noted that the current image leads to a reduction of 75% of CO_2 emissions, falling short of our target of 80%. The required additional 5% emission reduction can be obtained by installing carbon emission recovery units at the larger CHP installations. It must also be noted that a large part (about one third) of the remaining emissions are from non-energy use of energy carriers. We have assumed that the products made from these energy carriers are ultimately burnt, resulting in their carbon content to be released to the atmosphere. Potential carbon removal from waste incinerators or increased recycling of such products may also be an option to obtain the additional 5% of emission reduction. The large input of natural gas and biomass might result in an increase of emissions of other greenhouse gases (such as methane and N_2O), but measures to mitigate such emissions are assumed to be sufficiently implemented in 2050.

The image

Figure 3: The energy image quantified for the year 2050. Shown are sources, the energy carriers to which they are converted to and the economic sectors they are used in. The numbers represent energy consumption in EJ. Note that on the supply side (sources), numbers represent the consumption of primary energy carriers. On the demand side, numbers represent final energy consumption. The difference between input and output quantities in the conversion sector represents conversion losses. Note that the energy image shown, leads to a CO_2 emission reduction of 75%.

2.2 Fuel switch

Figure 4 shows the fuel mix in Europe in 1990 and 2050. The graphs show a large shift from oil to biomass for fuels and a shift from coal to natural gas and renewables. Total potentials



for fuel switching are shown in Table B.2 in the background document.

Figure 4: Fuel mix in Europe in 1990 and 2050.

2.3 Energy Efficiency

The energy efficiency of the economy as a whole is improving by 1.5%/yr. The efficiency of the energy supply system increases too. While final energy consumption stays at current levels, primary energy consumption decreases with about 35% compared to 1990. Table B.1 in the background paper shows the annual change rates by energy carrier by sector. Note that these change rates are the combined result of a change in energy efficiency, changes in structure and changes in activity level. Table B.3 in the background document shows potential improvements in specific conversion processes.

2.4 Structure and patterns

Shifts in structure and patterns are responsible for a 0.5%/yr reduction in final energy consumption. See Table B.1 in the appendix for a more detailed breakdown of changes by carrier and by sector (for a combination of energy efficiency effects, structural effects and activity effects).

2.5 Awareness, behaviour and lifestyle

Changes in behaviour will be one of the vehicles to implement the expected energy savings and emission reductions through fuel switch, energy efficiency improvement and structural change (see also Section 1.3).

Sustainable development is an important issue for a majority of the population and is acted upon at all layers of government. There is strong public support for CO_2 taxes and large and environmentally sound financial flows to developing countries.

Education and public-awareness policies play an essential role in international greenhouse-gas mitigation strategies. Green attitudes among a majority of the consumers have increased the speed of uptake of climate-friendly products and technologies throughout European countries.

40 per cent of the European population use computer-based programmes to define their individual carbon budgets. More than half of the consumers buy green electricity via green power schemes. One-third of citizens save their money in green equity funds which, due to green fiscal policies, provide a relatively high return on investment and invest in Clean Development Mechanism projects all over the world.

Sustainable development has become an obligatory subject in all primary and secondary schools in Europe. The subject addresses issues such as the global environmental situation, glocal development, intra- and intergenerational equity and the history of sustainable development. It also offers practical skills such as civic participation.

All municipalities in Europe have approved their own local Agenda 21+50. The local policy-makers rely on partnerships with citizen groups in implementing schemes for, for example, energy efficiency and renewable energy. At many places environmental consultancy shops are operating. Many activities at the local level are supported by the regional and local branches of the European Bank for Sustainable Development.

The environment has emerged as the most important political issue in all European countries. Because of a number of serious natural disasters, which have been attributed to the ffects of climate change, public pressure in Europe has forced governments at all levels to apply strictly the precautionary principle. Europe is pressing other political regions to do the same.

- Sustainable development and the precautionary principle are guiding principles for policy.
- Green consciousness and values are widespread.
- Widespread application of ICT enhances efficiency of movements.
- Fiscal policies promote green investments, including in environmentally friendly transport systems.
- Road pricing and other measures in order to internalise externalities are generally accepted.
- Tele-shopping is a natural part of everyday life.

Context

There are tendencies today in this direction, but there are also contradicting tendencies. Conditions that would strengthen the inclinations stated above are, for example, more apparent greenhouse effects, strong scientific evidence for the role of CO_2 in this context and a responsible and cooperative attitude among world leaders.

Changes in values and lifestyles cannot be enforced, but education, information and opinion-forming campaigns may help.

Awareness, values and lifestyles can also negatively influence energy consumption and emissions. Negative effects related to awareness, values and lifestyles could arise from:

- resistance to change
- threatened interests (e.g. fossil fuel industry)
- risk perception (security of supply, safety risks, economic risks)
- biodiversity (biomass energy)/bird safety (wind power)/protected area and loss of habitat (hydro power)
- visual impact (wind power)

2.6 Profile of the Image

Table: Overview of the main elements of the energy image

Elements	**Contribution to target fulfilment**	**Facilitating measures**	**Forces against this element**
1.Fuel substitution			Conventional energy suppliers
natural gas	very important	carbon tax, environmental regulation (sulphur, particulates)	utilities (import dependency)
biomass	very important	Non-Fossil Fuel Obligation (NFFO), the use of set-aside agricultural subsidies	utilities, competition with other uses (food, materials, sinks), environmentalists (loss of biodiversity)
hydro	some importance	carbon tax, NFFO	local residents, environmentalists (loss of habitat)
wind	some importance	carbon tax, NFFO, subsidies	utilities (security of supply), local residents (visual impact), environmentalists (bird safety)
solar	some importance	carbon tax, NFFO, subsidies	utilities (security of supply), architects, building corporations
electric heat pumps	important	subsidies, agreements with architects, building corporations	suppliers of conventional heating systems, building corporations
2.Energy efficiency			
supply side	important	efficiency standards, energy tax	liberalised energy market
demand side	very important	efficiency standards, energy tax	

3. Structures and patterns • energy-extensive industry • increased recycling, refillable packaging • increasing lifetime through higher quality products and reparability	important	tax base reform	energy-intensive industry, ministry of economic affairs shop keepers producers of short-lived products
4. Awareness, values and lifestyles	very important as a prerequisite for the other elements	information campaigns green labelling	suppliers of less environmentally friendly, but more convenient alternatives

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Appendix I: Background information on the Energy Image

B.1 The energy image

For the industry sector important drivers are:

- Production level
  The more products (such as steel, electric appliances, bread, etc.) are manufactured, the higher the energy consumption will be.
- Share of light industry/economic structure
  Light industry consumes less industry per unit of production than heavy industry. Also within the light and heavy subsectors differences in economic structure can occur that influence energy consumption. Examples are the share of the cement industry versus the share of the (more energy-intensive) aluminium industry, or in the chemical industry the share of the petrochemical industry versus the share of the pharmaceutical industry.
- Energy efficiency
  The higher the efficiency, the lower the energy consumption per unit of production will be.
- Material efficiency
  By reducing the amount of new material used in the manufacturing of a product energy can be saved. Examples are bottles out of thinner glass or garbage bags out of recycled plastics. Energy consumption can also be influenced by substituting one material for another (plastic bottles instead of glass bottles or wooden chairs instead of plastic chairs). A third option to influence energy consumption is by extending the lifetime of products, either by increasing product quality and repairability or by producing re-usable/refillable products. Note that part of these changes also require adjustments on the consumer side of the economy.

Important drivers for the transport sector are:

- The number of trips in both passenger transport and freight transport
  The number of trips is determined by the amount of people and freight to be transported and the occupancy rate. Occupancy rate tends to drop when the number of cars increases.
- The distance travelled per trip;
- Modal split
  The share of road transport versus rail transport versus maritime transport versus air transport.
- Vehicle size and type
  Larger (i.e. heavier) and more luxurious cars will require more energy without necessarily increasing occupancy rate.
- Energy efficiency
  The lower the energy consumption per km per type of vehicle the lower the energy consumption will be.
- Spatial planning
  Spatial planning partly determines the demand for transport services. An infrastructure mainly based on large malls on the outskirts of town will lead to a higher energy consumption than when local shops provide goods and services to residents.

For the buildings sector important drivers are:

- Population size
  A larger population size means more energy consumption for cooking, washing, showering, etc.

- Household size
  Larger households use less energy per capita than smaller households (less living rooms to be heated, a higher capacity load for washing machines, etc.)
- Home size
  Larger homes require more energy for space heating, lighting, cleaning.
- Amount of workspace
  More workspace results in a higher energy consumption for heating, ventilation, air conditioning, lighting, cleaning.
- Number of appliances
  Together with the frequency of use, the number of appliances in both homes and workspace is an important factor in electricity consumption in buildings.
- Energy efficiency
  The lower the energy consumption to heat or light a certain area or use an appliance, the lower building energy consumption will be.

Important drivers of agricultural energy consumption are:

- Farmland area
  The larger the farmland area the higher the energy consumption for farm vehicles and machinery will be.
- Type of crops
  The type of crops will determine the number of operations necessary for processing.
- Number and type of livestock
  The amount and type of livestock will determine energy consumption for heating stables, milking, etc.
- Intensiveness
  Energy consumption will also be determined by the characteristics of farming (greenhouses vs. conventional farming, free-ranging animals vs. stables).

Almost all of these drivers can be subject to policies in order to reduce energy consumption, although some may be less socially acceptable (e.g. population size). Based on expectations on technical, economic as well as social developments (autonomous or policy-driven) we estimated how the consumption of different types of energy carriers in each sector would develop. Table B1 shows the expected annual change rates for different energy carriers by sector.

Table B1: Rate of change in final energy consumption between 1990 and 2050 by carrier and by sector and total final energy consumption. A negative change indicates a reduction in energy consumption. Note that the change rates listed here are the result of combined changes in activity level (e.g. more transport), structure (e.g. different products in industry) and energy efficiency.

Carrier	Sector	Category	Rate of change (%/yr)	Final energy consumption in 2050 (EJ)
Heat	industry	Low temperature	-0.5%	0.2
		High temperature	-0.5%	1.5
		Steam	-0.5%	2.0
	Residential	Low temperature	-1.5%	3.0
	Tertiary + agriculture	Low temperature	-1.5%	1.1
	Total			**7.9**
Electricity	Industry		0.8%	4.7
	Residential		0.8%	3.0
	Tertiary + agriculture		1.0%	2.9
	Total			**10.7**
Fuels	Industry		0.0%	2.7
	Residential		-1.0%	0.2
	Tertiary + agriculture		-1.0%	0.2
	Transport		0.4%	9.3
	Total			**12.4**
Total				**30.9**

Additional assumptions for 2050:

- About 55% of industrial heat demand is high temperature heat, 40% is steam and 5% is low-temperature heat. In the other sectors only low temperature heat is used.
- 25% of transport fuels is aviation fuel and cannot be delivered by biomass.
- Gas-based CHP has an electric efficiency of 60% and a heat-efficiency of 30% (conventional gas-based electricity generation – not in our current image – has an electric efficiency of 70%). Biomass-based efficiencies are 50% for electricity and 30% for heat.
- Electrical heat pumps have a coefficient of performance of six.

Table B.2: Fuel switching potentials in electricity production (potential effect of switching TO the listed fuel). As far as available, cost estimates are also shown, as well as additional remarks regarding potential consequences.

Category	Potential	Costs	Remarks
Fossil fuels Gas	Technical potential: about 270 Mt CO_2 (replacing all current coal capacity)		Current CO_2 emissions from coal-based electricity about 670 Mt CO_2 World gas reserves (proven) 5000 EJ, in Western Europe about 250 EJ. Current EU gas consumption 10 EJ/yr. Increasing import dependency
Nuclear	Technical potential 1 Gt CO_2 (replacing all fossil fuel-based capacity)		Current emissions from fossil fuel-based electricity about 1 Gt CO_2 Liberalised electricity market poses barrier Public acceptability Risk of non-proliferation
Hydro Large-scale Small-scale	Techn.pot: 910-1280TWh (32-48% in use) Economic pot.: 640 TWh (63% in use) Economic pot. 75-85 TWh (20% in use)	?	Loss of habitat Risks of earthquakes Part of potential may be protected area (e.g. in Scandinavia)
Wind	Gross Electrical Potential 9000TWh/yr 1st order potential (GEP minus physical constraints) 555 TWh/yr (on shore) 2nd order pot (GEP minus social/environm. Constraints) 180 TWh (on shore) Off shore: 2800 TWh	Current cost: 0.05 ECU/kWh Probably higher	Fluctuation in supply Bird safety Noise Includes potential at more expensive locations.
Solar[1] PV Thermal-electric	Techn.potential >total energy consumption 240 TWh/yr in 2050 > 100GWe in Mediterranean	 Expected costs <0.10 ECU/kWh	Fluctuation in supply Requires about 55 million houses (1/4th total number) to have a 4 kW (20 m^2) PV panel

Biomass[2] Waste Energy crops	30% of primary energy cons. in 2050 for EU: 300 Mtoe (12 EJ) for EU 1/3rd of total biomass used (4 EJ for EU) 2/3rd of total biomass used (8 EJ for EU)	Biomass for electricity 5-10 $-cents	Land requirements (competition with food and material supplies) 15% of land now in use in forests (now 157 Mha) 40% of land now in use in crop land (now 140 Mha) total: 80 Mha (17% of total land) estimated long term excess crop land: up to 65 Mha Loss of biodiversity Water requirements
Other Tidal Geothermal	 Techn.pot. 60 TWh/yr Techn.pot >>primary energy demand Realistic pot. 0.5 EJ	 0.05-0.15 ECU/ kWh ?	 Conflicts with shipping/navigation

Notes: [1] Not included is solar thermal energy (solar boilers). The potential for this is estimated at 0.6 EJ; [2] Biomass figures for electricity and fuel combined, except when otherwise noted. Cost figures for bio-fuels are 0.14 ECU/l bio-oil (current prices) from waste and 0.5 ECU/l bio-ethanol from energy crops (regular gasoline-diesel 0.07 ECU/l before taxation).

Table B.3: Energy efficiency of conversion processes and potential future developments

Energy resource	Process	Energy carrier	Current efficiency	Potential efficiency 2050
Fossil fuels				
Coal	Combustion	Electricity Steam Warm water	45%	
	Gasification	Methanol Hydrogen	50%	
Oil	Combustion			
Gas	Combustion	Electricity Warm water Steam	55%	
		Methanol Hydrogen	60%	
Biomass	Extraction from oil-rich plants	Bio-oil		

	Biochemical conversion Thermochemical conversion Pyrolysis Anaerobic digestion Combustion Gasification	Ethanol Methanol Hydrogen Biocrude Biogas Electricity Warm water Steam Electricity Steam Cogen-mode	 40-54% 14-18% (steam turbine) est. 33-43% est. 29-34% est. 29-38%	 34% 55% 50-60/30%
Electricity Nuclear Renewables	Electrochemical conversion	Hydrogen	70-75%	90-95%

Table B.4: Potential for emission reductions from changes in structure & patterns

Category	**Application**	**Remarks**
Change in Economic structure	Stimulating higher value-added industries, more knowledge-intensive or service-oriented economy	Dislocation of heavy industries
CO_2 removal And disposal	Large plants	Often transport from production site to storage site is required. CO_2 stored in oceans may influence ocean/atmosphere equilibrium. Estimated capacity in Western Europe 50-2600 Gt CO_2