World and European Energy and Environment Transition Outlook

WETO-T

The World and European Energy and Environment Transition Outlook (WETO-T) offers a new perspective on the technological, economic and social options which could lead towards a post-carbon society by the end of the century.

WETO-T tackles demographic, human capital, and lifestyles issues up to 2100 and the consequent needs for energy services worldwide.

For Europe, the WETO-T report firstly addresses three technology paradigms for long-term sustainability. Secondly, it analyses the energy-environment transition in combination with land-use issues. Thirdly, it helps to understand the "social fabric" of this energy-environment transition.

WETO-T also investigates the potential innovations in the transport and building sectors in conjunction with changes in human behaviour. Finally, it looks at the policy path to the achievement of the climate change targets.
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World and European Energy and Environment Transition Outlook

WETO-T

Bertrand Château and Domenico Rossetti di Valdalbero (Eds.)
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# Table of contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Executive summary</td>
<td>3</td>
</tr>
<tr>
<td>Foreword</td>
<td>9</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>11</td>
</tr>
<tr>
<td>Introduction</td>
<td>12</td>
</tr>
<tr>
<td>Part 1 – Forward-looking on very long term energy and environment issues</td>
<td>14</td>
</tr>
<tr>
<td>1.1 Chapter 1 – Methodological precautions in looking forward to 2100</td>
<td>14</td>
</tr>
<tr>
<td>1.1.1 Forward-looking over a whole century is necessary and feasible,</td>
<td>14</td>
</tr>
<tr>
<td>but precaution is advisable</td>
<td></td>
</tr>
<tr>
<td>1.1.2 Heritage and degrees of freedom: accounting for temporalities over one century</td>
<td>17</td>
</tr>
<tr>
<td>1.2 Chapter 2 – Assessing fundamentals of needs over 100 years</td>
<td>19</td>
</tr>
<tr>
<td>1.2.1 Addressing the needs of energy services</td>
<td>19</td>
</tr>
<tr>
<td>1.2.2 Demography, urbanisation and human capital</td>
<td>21</td>
</tr>
<tr>
<td>1.2.3 Behaviour, lifestyle and time use structure</td>
<td>28</td>
</tr>
<tr>
<td>1.2.4 Economic development and welfare</td>
<td>33</td>
</tr>
<tr>
<td>1.3 Chapter 3 – Need for energy services up to 2100</td>
<td>36</td>
</tr>
<tr>
<td>1.3.1 Measuring the need for energy services</td>
<td>36</td>
</tr>
<tr>
<td>1.3.2 Food and eating</td>
<td>36</td>
</tr>
<tr>
<td>1.3.3 Shelter</td>
<td>38</td>
</tr>
<tr>
<td>1.3.4 Self-fulfilment</td>
<td>40</td>
</tr>
<tr>
<td>1.3.5 Mobility</td>
<td>41</td>
</tr>
<tr>
<td>1.3.6 Other economic production</td>
<td>45</td>
</tr>
<tr>
<td>1.3.7 Visions of the world in 2100: uncertainties and consequences for energy-related needs</td>
<td>46</td>
</tr>
<tr>
<td>1.4 Chapter 4 – Three technology paradigms for long-term sustainability</td>
<td>52</td>
</tr>
<tr>
<td>1.4.1 From energy services to energy demand</td>
<td>52</td>
</tr>
<tr>
<td>1.4.2 Continuing the fossil fuels paradigm</td>
<td>55</td>
</tr>
<tr>
<td>Section</td>
<td>Page</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>1.4.3 Nuclear power and hydrogen as a new possible paradigm</td>
<td>61</td>
</tr>
<tr>
<td>1.4.4 Renewable energy flows as the core of a green paradigm</td>
<td>64</td>
</tr>
<tr>
<td>Part 2 – Energy and environment transition in the EU to 2050</td>
<td>70</td>
</tr>
<tr>
<td>2.1 Chapter 1 – Technological innovations and related behaviour</td>
<td>70</td>
</tr>
<tr>
<td>2.1.1 Innovations in building and housing</td>
<td>70</td>
</tr>
<tr>
<td>2.1.2 Innovations in mobility</td>
<td>75</td>
</tr>
<tr>
<td>2.2 Chapter 2 – Energy environment transition and land-use issues</td>
<td>88</td>
</tr>
<tr>
<td>2.2.1 Human settlements and urbanisation: moving towards low carbon cities</td>
<td>88</td>
</tr>
<tr>
<td>2.2.2 Renewable energy and the competition for land</td>
<td>94</td>
</tr>
<tr>
<td>2.3 Chapter 3 – The social fabric of the energy and environment transition</td>
<td>108</td>
</tr>
<tr>
<td>2.3.1 Enablers and obstacles: insights from anticipatory experiences</td>
<td>108</td>
</tr>
<tr>
<td>2.3.2 Perceptions, fears and trust of European youth</td>
<td>123</td>
</tr>
<tr>
<td>2.4 Chapter 4 – History and meaning of the 2°C target policies</td>
<td>129</td>
</tr>
<tr>
<td>2.4.1 Origins of the long term climate targets in Europe: Factor 4 or 80% reduction in 2050</td>
<td>129</td>
</tr>
<tr>
<td>2.4.2 The policy path to the 2°C target</td>
<td>137</td>
</tr>
<tr>
<td>List of acronyms</td>
<td>145</td>
</tr>
<tr>
<td>Figure 1.1</td>
<td>Time and uncertainty in forward-looking methodologies</td>
</tr>
<tr>
<td>Figure 1.2</td>
<td>Evolution and distribution of the world population by region</td>
</tr>
<tr>
<td>Figure 1.3</td>
<td>Distribution of the population by class of age</td>
</tr>
<tr>
<td>Figure 1.4</td>
<td>Distribution of the households according to age of head of household</td>
</tr>
<tr>
<td>Figure 1.5</td>
<td>Number of person per household (2000-2100)</td>
</tr>
<tr>
<td>Figure 1.6</td>
<td>Urbanisation rate (2000-2100)</td>
</tr>
<tr>
<td>Figure 1.7</td>
<td>Enrolment of the young in tertiary education (2000-2100)</td>
</tr>
<tr>
<td>Figure 1.8</td>
<td>Evolution of the information index (2000-2100)</td>
</tr>
<tr>
<td>Figure 1.9</td>
<td>Percentage of active people out of total population (2000-2100)</td>
</tr>
<tr>
<td>Figure 1.10</td>
<td>Time use for food and information (2000-2100)</td>
</tr>
<tr>
<td>Figure 1.11</td>
<td>Time use for labour and information (2000-2100)</td>
</tr>
<tr>
<td>Figure 1.12</td>
<td>Time use for self fulfilment and information (2000-2100)</td>
</tr>
<tr>
<td>Figure 1.13</td>
<td>Time use structure, Worldwide, up to 2100</td>
</tr>
<tr>
<td>Figure 1.14</td>
<td>Index of use of human capital (2000-2100)</td>
</tr>
<tr>
<td>Figure 1.15</td>
<td>Economic development (2000-2100)</td>
</tr>
<tr>
<td>Figure 1.16</td>
<td>Need for energy services for food and time budget (2000-2100)</td>
</tr>
<tr>
<td>Figure 1.17</td>
<td>Need for energy services for food according to energy service category (2000-2100)</td>
</tr>
<tr>
<td>Figure 1.18</td>
<td>Need for energy services for shelter and economic development (2000-2100)</td>
</tr>
<tr>
<td>Figure 1.19</td>
<td>Need for energy services for shelter according to energy service category (2000-2100)</td>
</tr>
<tr>
<td>Figure 1.20</td>
<td>Energy needs for self fulfilment and time budget (2000-2100)</td>
</tr>
<tr>
<td>Figure 1.21</td>
<td>Energy needs for self fulfilment and information index (2000-2100)</td>
</tr>
<tr>
<td>Figure 1.22</td>
<td>Need for energy services for transport (2000-2100)</td>
</tr>
<tr>
<td>Figure 1.23</td>
<td>Passenger mobility and economic development (2000-2100)</td>
</tr>
</tbody>
</table>
Figure 1.24  Passenger mobility per mode (2000-2100) 44
Figure 1.25  Freight mobility and economic development (2000-2100) 44
Figure 1.26  Freight mobility per mode (2000-2100) 44
Figure 1.27  Need for energy services per unit of economic production and information (2000-2100) 45
Figure 1.28  Need for energy services per exergy levels (2000-2100) 46
Figure 1.29  Overall need for energy services per capita (2000-2100) 47
Figure 1.30  Distribution of overall needs of energy services per world region (2000-2100) 48
Figure 1.31  Distribution of overall need for energy services per density (D) / unit power (P) categories 48
Figure 1.32  World population and households in the three scenarios (2000-2100) 49
Figure 1.33  World needs for energy services in the three scenarios (2000-2100) 50
Figure 1.34  Energy use (in primary energy terms) for the manufacture of bulk materials 53
Figure 1.35  Specific energy consumption of transport modes in Europe, 2000 and 2100 54
Figure 1.36  Energy-related CO₂ emissions in the EU in 2009 56
Figure 1.37  Development of the efficiency of the steam cycle 58
Figure 1.38  Highlights of primary energy supply in Europe in the fossil paradigm by 2100 59
Figure 1.39  CO₂ emissions and storage in Europe in the fossil paradigm 60
Figure 1.40  Major milestones for a sustainable continuation of the fossil fuels paradigm 60
Figure 1.41  Electricity supply in the fossil paradigm with fusion 61
Figure 1.42  Major milestones for a high fossil case with additional fusion power 61
Figure 1.43  Highlights of primary energy supply of Europe in the nuclear and hydrogen paradigm by 2100 63
Figure 1.44  Milestones of the nuclear and hydrogen paradigm  
Figure 1.45  Electricity production from renewable sources, EU27, 2009  
Figure 1.46  Highlights of primary energy supply of Europe in the renewables paradigm by 2100  
Figure 1.47  Highlights of the use of biomass in Europe in a renewables paradigm by 2100  
Figure 1.48  Highlights of the electricity sector in a renewables paradigm in Europe, 2100  
Figure 1.49  Milestones of renewable paradigm  
Figure 2.50  Technological requirements for meeting standards up to 2030  
Figure 2.51  The 3 technologies for automotive  
Figure 2.52  The hybrid vehicles  
Figure 2.53  Technology innovation and transport modes  
Figure 2.54  Electric solution as alternatives to ICE  
Figure 2.55  Urban structure by number of centres and level of concentration  
Figure 2.56  Envisioning the urban forms  
Figure 2.57  Balancing energy flows between urban and rural areas  
Figure 2.58  Balancing energy flows between high and low density urban areas  
Figure 2.59: Sparse vs Compact Housing new constructions in some European countries in 2003  
Figure 2.60  Solar potential in the World  
Figure 2.61  Wind potential in Europe  
Figure 2.62  Overview of biomass flows and the global land surface  
Figure 2.63  Eventual temperature change depending on GHG concentrations  
Figure 2.64  Contribution of options to CO₂ reduction – POLES model, ADAM project  
Figure 2.65  Contribution of options to CO₂ reductions – IEA, ETP2008
Figure 2.66  Final energy consumption – ADAM (POLES): Baseline and constrained scenarios  

Figure 2.67  Primary energy consumption – ADAM (POLES): Baseline and constrained scenarios  

Figure 2.68  Impact of carbon policies on long-term oil market (POLES model, from ADAM study)  

Figure 2.69  Gas and coal consumption in the ADAM Baseline and 400ppm scenarios (POLES)  

List of Tables

Table 1.1  Specific energy use and share of new buildings entering the stock in Europe for the years 2000 and 2100  
Table 1.2  Table of energy reserves and resources  
Table 2.3  EU Pathway of building concepts for new and existing buildings  
Table 2.4  Investment needs in sustainable mobility scenarios, France  
Table 2.5  Renewable energy sources and land-types  
Table 2.6  Burden sharing between Annex I and Non Annex I countries
Addressing energy and environment transition issues requires producing visions over a very long time period, certainly beyond 2050 and likely to the end of the century. How will demography, human capital, and life-styles drive the needs for energy services worldwide over the 21st century, and with what uncertainty? How could the world energy system fulfil these needs in a sustainable way? What does this imply regarding the necessary and possible energy transitions away from fossil fuels in Europe; and what are the social, technological, and policy dimensions of these transitions? These are the main questions addressed in WETO-T.

Three times more energy services in 2100 compared to today

According to the United Nations, the world population will peak at 8.7 billion sometime around 2050 if the so-called “demographic transition” continues everywhere (medium variant). This will bring deep changes in the world population structure: geographical balance, overall ageing (the percent of the world population older than 50 years will jump from 18% to 42%), sharp declines in households’ size (the percent of households with one or two person will increase from 37% to 63%), and an increasing urbanization rate (from 47% to 75%).

Such a demographic evolution, together with the considerable increases in education (and therefore labour productivity) and participation of women in the labour market that go along with the demographic transition, will drive a huge increase of “human capital” availability. The resulting creation of wealth will be huge, potentially multiplied by eight over the century. As a consequence, the overall needs of energy services for the world might be multiplied by 3.2, between 2000 and 2100. The energy needs per capita, which ranged globally from roughly 10 to 110 in 2000, would be multiplied by 2.4 over the century; with a drastic reduction in the gaps among world regions by 2100, between 35 and 140 times. The needs of energy services related to mobility and self-accomplishment (culture, leisure, communication, information, etc.) will grow even faster and be multiplied by 8 and 15, respectively, over the century. The energy service need per unit of wealth is calculated to decrease by –0.9% per year on average throughout the world. This is very close to the average decrease of the GDP energy intensity in industrialised countries during the 20th century.
Three technology paradigms for long term sustainability in Europe

Technologies used to fulfil the needs of energy services are partly determined by the availability of resources involved in the energy system. Together, they constitute the so-called “energy-technology paradigm”. Therefore, this paradigm will determine both the amount and structure of the physical energy resources required for a given set of energy service needs.

Fossil fuels may continue to be the core of the system, even with the perspective for oil and gas peaking well before the end of the century, thanks to the huge coal resources worldwide. But then only limited progress can be expected in decoupling energy demand from the needs of energy services, and a continuation of the current energy-technology paradigm. However, in order to avoid climatic disaster the vast amount of carbon that needs to be stored is enormous, far beyond the sustainable storage capacities known today.

If Carbon Capture and Storage (CCS) remains limited for technical or economic reasons or because of a lack of public acceptance, then nuclear electricity and hydrogen could become the core of a new paradigm. But, as shown by Fukushima, enormous progress is still required on security and waste management/destruction to make such a paradigm sustainable. Electricity goes along with higher end-use efficiency, but there is no reason why a nuclear paradigm would bring drastic changes in the end-uses technologies. Therefore, only limited progress can be expected in decoupling electricity and hydrogen demand from needs of energy services.

If both a CCS breakthrough and nuclear sustainability do not occur rapidly enough, renewables and energy thriftiness might be the only solution to avoid major environmental disasters (and then these would take the lead of a green paradigm). Renewables and energy thriftiness would induce a totally different way of supplying needs of energy services, contributing to decouple energy demand from needs of energy services. Renewables potentials are huge, orders of magnitudes larger than any anticipated energy demand in the future. Still a number of serious challenges remain, which have to be overcome before renewable energies can supply major fractions of the energy demand: power density of the flows as compared to the power density of the needs of energy services, intermittency, and diffuseness.
Innovations in technologies and related behaviours

A transition to a low carbon society by 2050, based on renewables and energy thriftiness, implies changes in household behaviours towards thriftiness and a large-scale adoption of low energy technologies, in particular in buildings and transport.

Renovation of existing buildings will form a large part of energy demand reduction in housing. For new constructions, concepts such as passive, zero-energy, and plus-energy buildings, will become common. Zero and plus-energy housing concepts are designed to produce energy, allowing households to become suppliers as well as consumers in the energy market. This requires a different legal basis and may also require active decision making by the household energy system. Smart metering technologies will enable automated operation.

In transport, biofuels for internal combustion engines and new technologies using different energy sources and carriers will develop. Technologies based on centralized and decentralized renewables, such as electricity (battery vehicles and plug-in hybrids) and hydrogen (fuel cells), will have a key role in the paradigm change. Switching from storable motor-fuels to non/hardly storable energy carriers will have deep consequences in the organisation of the whole transport-energy system. In that respect, the development of multiple car ownership and the increasing share of urban and sub-urban car trips favour the market perspectives of these new electrified technologies.

Average speed is a key driver in mobility development, both for persons and for freight, and shows a long-lasting and fairly stable statistical correlation with GDP. If this relation continues, electro-mobility innovations will not be enough to reach ambitious carbon targets by 2050. This would require instigating changes in social behaviours in order to mitigate the growth of mobility without reducing the growth of the GDP. That is, “decoupling” first the growth of average driving speeds for persons and goods from GDP, and if necessary, decoupling mobility itself from GDP. This implies that people can find the same opportunities at shorter distances and with lower speeds, as they would have found further and faster in “business-as-usual” development. This is mostly a matter of land-use decisions.
Energy-environment transition and land-use issues

Rethinking how we create our built environment is critical to the success of the deployment of innovations related to buildings and transport. Uncontrolled urban sprawl will lead to a real socio-economic collapse when cheap fossil fuels become scarce, unless electromobility coupled to photovoltaic sources is sufficiently available beforehand. Ruralised city form with a diffuse city pattern may also be a possible response to oil shortage, provided that sparse settlements are based on a more sustainable semi-rural lifestyle and electro-mobility relies increasingly on local production from solar or wind energy. In compact city form, all necessary services are within a short distance and all institutions for supporting such centres are available locally. Finally, in network city form, people will have access to jobs and services by transit or walking, as well as by using electric cars for short journeys. Intercity movements will move toward fast electric rail and will be reduced considerably by the new generation of high quality interactive video conferencing.

In a green paradigm based on renewables and energy thriftiness, the energy system will have to be increasingly re-balanced between urban and rural areas. Both areas would increase their renewable energy collection, while traditional energy supply from rural areas (i.e. centralized CO₂ emitting technologies) would dramatically decrease. Energy would more and more be produced in-situ, with networks ensuring the remaining necessary energy is transferred between areas.

The social fabric of the energy and environment transition

“Anticipatory experiences” of energy transition conducted throughout Europe are important to understand how the post-carbon transition as a whole may happen. First, energy transition is not merely a technological process, but more a general process of technology transfer, in which each technical step requires action or has organisational, economic, social, and cultural implications. Second, politics is certainly no less important than technology in energy transition. Political decisions have to be taken at the right time and in the right direction, need to involve key stakeholders, and anticipate and interpret demands from different economic and social sectors.
Moving towards a new post-carbon energy paradigm will require deep changes in people’s behaviours. This is a long process that starts at school. A survey was carried out in the PACT project to understand what the situation in this regard is in Europe today. The first clear message is that children today are rather confused about the challenges ahead regarding oil depletion and climate change. The second message is that they see any future different from today’s conditions negatively, and therefore are reluctant to accept any paradigm change. The third message, which is optimistic, is that children place great trust in science and knowledge, which confirms the centrality of school within the network of educational references. They consider school as a medium in the journey between their current daily experiences and their future adult lives.

**Policies and transition: lessons from the 2°C target**

As the global mean temperature increases, so will the number and amplitude of negative impacts mankind will have to face. The certainty that climate change is human-induced has been progressively strengthened by the IPCC (reaching “very likely” in the fourth assessment report). An indicative target of temperature increase of +2°C (compared to pre-industrial average temperature) has been indicated to be sufficient to avoid significant impacts. This objective is explicitly considered by the European Union, and mentioned in the Copenhagen Accord. The scientific community has shown that long term GHG concentrations should be stabilised at 450 ppm CO₂-e in order to conserve a 50% probability of remaining below this 2°C increase threshold. Emission reductions for Annex 1 countries compatible with a 450 ppm CO₂-e stabilization level in 2050, assume a minimum reduction of 80% with respect to 1990 emission levels.

The dramatic shifts in lifestyle and development patterns corresponding to a transition to low carbon economies call for an extremely ambitious policy action, in both its scope and coverage. First and foremost, a requisite for efficient action is some degree of coordination in the policy process. In economic terms, the primary aim is that emissions should be reduced in those places where it is the cheapest to do so. Second, timing will be critical, even accounting for the slack given by the ongoing global economic crisis. Delayed action continually
closes windows of opportunity to reach lower concentration levels, while it increases the costs of the options left available. Third, the distributive consequences of ambitious climate policies should be duly assessed and controlled as much as possible: for households, to shield poorer parts of society from strong direct impacts on their living standards; for firms, to prevent unilateral action which overly degrades their competitiveness; for governments, to guarantee that climate policies neither deteriorate (through subsidies and tax cuts) nor improve (through tax and auction proceeds) public budget balances. Last, there is a need for pedagogy; for public opinion to accept the proposed policy portfolio, it will have to be sufficiently straightforward. This, together with its theoretical properties, naturally points to some generalised form of carbon pricing as the core of any policy action. However, without doubt some more targeted policy measures will be required to tackle a number of market failures and imperfections that bar the way to achieving some abatement potential at moderate cost.
As a member of the European Commission, I give utmost importance to the Europe 2020 strategy and the European targets for reducing greenhouse gas emissions, for increasing the share of renewable energy sources, and for improving energy efficiency.

European research and innovation is strongly supporting the development of clean energy technologies, sustainable transport systems and better understanding of the climate change phenomenon. The upcoming “Horizon 2020” – the framework programme for research and innovation – will specifically address these societal challenges.

But when dealing with the nexus between energy, environment, transport and land-use, we need a more complete vision of what our future might look like. Forward-looking research work support strategies on the so-called “post-carbon society”, on the options to fight against climate change and to ensure a better energy security of supply.

The “World and European Energy and Environment Transition Outlook” provides fresh insights and complements with a longer-term perspective the European Commission Communications related to a low carbon economy in 2050 and on the future of transport. It analyses important aspects for the Innovation Union and the Resource Efficient Europe flagship initiatives of the Europe 2020 strategy.

Among the messages coming from this report and in view of the “Rio+20” conference on sustainable development, I am particularly concerned by the fact that world energy needs may triple by the end of this century. Energy prices and the risk of conflicts could escalate as competition for scarce resources intensifies.
Knowing that the energy needs for mobility worldwide could more than quintuple by 2100, I am also looking at the potential research and innovation actions related to the establishment of future settlements and on sustainable urbanisation. This is particularly relevant in emerging countries and Europe could contribute with its best-practices in urban management.

The pages that follow demonstrate that with strong efforts towards technological and social innovation, a decoupling of economic growth and energy consumption is possible and would be beneficial. Europe could then take the world leadership in the green markets while ensuring at the same time the protection of the earth, economic development and the well-being of its citizens.

*Máire GEGHEGAN-QUINN
Commissioner for research, innovation and science*
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Both VLEEM and PACT have been coordinated by Bertrand Chateau from Enerdata and have been managed and supervised by Domenico Rossetti di Valdalbero and Pierre Valette from the European Commission, DG Research and Innovation.

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Introduction

The World and European Energy Environment Transition Outlook (WETO-Transition) is the latest report in the WETO series (World Energy Technology Outlook) series. The change of term to “transition” in place of “technology” arises from two core assumptions: that the transition away from the fossil fuel-based energy system is the principal challenge of the coming decades, and that this transition is not just about technology, but will include human behaviour and lifestyle, as well as global socio-economic organisation.

The European Union has sponsored a number of research projects over recent years to assess the transition from a sociological, economic, technical, and political perspective, by developing analytical concepts, preparing forward-looking methodologies and exploring the necessary scenarios. At the same time, several EU Member States have commissioned complementary studies aimed at providing a better understanding of the challenges in order to design appropriate policies, in particular with regards to climate change.

This report attempts to compile and synthesise the most striking results of the studies completed to date.

The first part of the report is based mainly on the results of the VLEEM[1] research projects (Very Long Term Energy Environment Modelling), sponsored by the European Commission DG Research and ADEME in France. It begins by considering the methodological implications of studies that attempt to address the very long term
(50 to 100 years). It then proposes reflections and quantitative figures for the dynamics of global energy services in the 21st century, mostly in relation to demography, human capital and time-use. Finally, it describes the structures that could dominate the worldwide energy scenarios by the end of the century.

The second part of the WETO-Transition report focuses on the social, technological and policy implications for Europe of the shift from a fossil-fuel based system to a post carbon society. It considers a shorter timeframe: up to 2050. This part of the report is based on the results of the FP7 research project “Pathways for Carbon Transitions” (PACT) (2), a major forward-looking study which addressed the feasibility and techno-economic implications of moves to make deep cuts in greenhouse gas emissions worldwide – as well as other studies from around Europe, in particular on the question of sustainable transport [PREDIT, France (3)].

This report investigates the links between social and technological innovations in housing and transport (chapter 1), land-use implications of the transition (chapter 2), the social fabric of the transition (chapter 3) and finally attempts to form a bridge between the analytical work on energy and environment transitions and current debate and policies on climate change (chapter 4).

Bertrand Château
Coordinator of VLEEM and PACT

1 Part 1
Forward-looking on very long term energy and environment issues

Any discussion of future developments in the fields of energy and the environment needs to consider scenarios that forecast well into the future, up to the end of the century.

But looking so far ahead is challenging and scientifically questionable. How, for instance, would people visiting the International Exhibition in Paris in 1900 have imagined the year 2000?

Some methodological considerations are necessary.

1.1 Chapter 1
Methodological precautions in looking forward to 2100

Do we really need to look almost a century into the future? If yes, does it make sense to try to quantify, or model, a situation, or should we restrict ourselves to qualitative foresight considerations?

1.1.1 Forward-looking over a whole century is necessary and feasible, but precaution is advisable

Forward-looking over the very long term is necessary

Forward-looking efforts are aimed at providing a basis for debates and decisions that seek to create the conditions required for future economic and social development. In the field of energy, this is true both for current energy policy decisions and R&D decisions.

Take, for example, developments in life expectancy, as well as the Human Development Indicator over the 20th century, which show that living conditions are improving throughout the world (with the exception of those parts of Africa most affected by AIDS and the former Soviet Union, due to the collapse of the political and social system).

Yet a number of factors challenge the assumption that this trend will continue:

- the world population is still growing: the UN predicts it will be in the range of 8–11 billion by 2050;
- the geographical scope of environmental damage is increasing: it has already reached a global level, and anthropogenic material cycles outweigh natural cycles[4];

the pace of change has accelerated: new materials, procedures and products are being developed increasingly rapidly, yet an analysis of their potential impact – damage to human health or the environment, for example – has not been completed (if it has even begun) before the product has gained a significant market share.

The common feature of these factors is that, while they have considerable implications for current policy decisions, they involve phenomena with a very strong inertia, with time ranges for inflexion or reversibility covering decades, if not centuries.

This highlights the (urgent) need to develop tools capable of rationalising debates and decisions that are likely to affect living conditions over very long time horizons.

As Swedish geographer Torsten Hägerstrand said: “When one, as we do today, has made long-term sustainability a crucial condition for societal development (at least rhetorically), then it is clear that we must strengthen how societal and environmental changes actually occur. Without such knowledge one cannot choose practical political means in a consistent manner. In such a development of knowledge the connection between technical change and social change becomes a key issue” [5].

How to define forward-looking over the very long term?

In the field of energy, the very long term is defined as the time horizon over which technologies not known today may alter the fundamentals of energy systems. Practically, it starts after 30 years, and its main milestones are the century and half-century.

In terms of what can be expected from making predictions over the very long term, consider the weather forecast. While weather can be predicted only by a few days, it is apparently possible to make much longer projections – one century, say – about climate trends. Such projections would not be able to predict the weather in any particular place at that time, however; talking about the climate is describing atmospheric phenomena in a much more aggregated way. Similarly, very long-term energy forecasting is more an analysis of the future climate of the energy system than a precise weather forecast of the energy markets.

Unlike the meteorological climate, however, science does not provide us with the means to predict social, political and technological developments over the coming decades (let alone the next century). Why then, undertake such studies, and can we give any weight to their results? Our goal, therefore, ought not to be an attempt to predict what the world will look like a century from now, but to develop tools which offer a fair chance to base current decisions on the best available knowledge. Studies in this area should offer an opportunity to discuss the potential of various technological or organisational structures, not predict what these structures will be.

Sustainability and back-casting: the key concepts of forward-looking over the very long term

Any discussion of what decisions should be taken now in order to impact the very long term – up to 2100, say – makes sense only insofar as such decisions would help create the conditions required to reach a certain desirable future, and prevent major turmoil between now and then; in other words, create the conditions of sustainable development.

Back-casting is a methodological approach designed to address sustainable development or, more generally, the concept of a desirable future. Its task is to define trajectories for the path between the existing system and a desired future system, which do not violate human rights, the principles of democracy or pluralism. The future is not seen as a utopia which must be realised at any cost, and no matter what the means.

The main reason for using a back-casting approach is to think first and foremost about necessary changes, and only at a subsequent stage about the problems that might arise from implementing those changes.

Political acceptance of the concept and methodology of back-casting is, of course, pre-requisite if any results of the back-casting study are to be linked with decision-making, especially in the R&D field.

In the energy sector, energy-related needs can be assessed using conventional forecasting, based on general but simple causal relations with demography, wealth and human behaviour. Back-casting should be used only to study the whole chain, from primary energy carriers down to energy services, the latter being taken for granted. Only the technology and the organisation of the energy chain (including end-use of energy) are relevant to discussions and decisions about sustainability, not population growth or human behaviour.

Nevertheless, it is necessary to clarify how the debate on the sustainability of energy systems over the very long term can be kept meaningful. What key elements would make personal and social life acceptable enough, around the world, a century from now, from a cultural, social, economic and geopolitical point of view, so that no major irreversible catastrophe, whether social, health, civil, military or geopolitical, occurs before the end of the century.

The concept of sustainable development should not be mistaken for an ideology that promises heaven on earth once it is realised. It is more a formal approach by which to judge decisions and which allows for freedom of choice between various alternatives.

A very general meaning of “sustainable development” was presented in the Brundtland report, “Our Common Future”, issued by the WECD[1], a commission set in place by the UN General Assembly in 1983. The report defines sustainable development as “a development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. Thus described, it is a concept of justice, which can only be justified by ethical means.

For the purposes of modelling and decision-making, however, it is necessary to describe criteria and indexes that translate the general definition into practical terms, responding to questions such as: what quantity of CO₂ can be emitted, how much radioactive material can be produced, what portion of land should be covered by energy conversion and transport technologies, and so on.

**Knowledge and uncertainties according to time horizon**

With what confidence can we make projections into the future, and how does this change as we extend the time horizon forward to the very long term? The limits of our knowledge are the primary factor: knowledge embodied in the way we describe the world, and knowledge of future possibilities taking account of external variables. Then there is uncertainty: uncertainty regarding the gap between a simplified description of the world and its actual complexity, and uncertainty about the range of future possibilities for external variables.

In the short term (less than three years), the behaviour of the energy system is mostly determined by relatively unchanging socio-economic structure and technological landscape. The system can thus be described in statistical terms, using historical data that takes account of significant influences, and pays little attention to causalities, except for conjunctural fluctuations: climate, short business cycles and so on.

Extending the time horizon to the medium term (i.e. 3-10 years) changes the perspective. The energy system is still strongly influenced by the inertia of socio-economic structures and the technological landscape, but significant changes may come about as a result of policy or business

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decisions. Statistically based forward-looking analysis remains a robust technique, but this must be enhanced by accounting for causalities related to decisions.

Extending the time horizon further, to 30 years, say, raises new challenges. The influence of inertia is fading away, and there are a greater number of possible outcomes due to the evolution of socio-economic structures and technology. What the possibilities are, what will drive them, and what consequences they might have on the energy system become key issues. Describing the world using statistical analysis based on historic data is less and less reliable, as it may differ significantly from the way the world actually functions. This is where it becomes necessary to describe causalities in detail. At the same time, there will be growing uncertainty about the cause of any changes. This uncertainty remains manageable: to a large extent, decision-makers who will influence the evolution of socio-economic structures and technology are already in place, and their decisional behaviours can be known. Meanwhile, the proportion of individuals with a value system and preferences that are radically different from those known today will remain very small (generational change takes a minimum of 25 years), and the proportion of entirely new technologies that we cannot describe today will also remain very small (it takes 30 years from scientific discovery to industrial application on the market).

When it comes to looking beyond 30 years, however, we need a change in the forward-looking paradigm. There is growing uncertainty about possible changes in socio-economic structures and technologies, and this uncertainty can no longer be managed in the same way, due to an irreducible lack of knowledge about decisional behaviour, value systems and preferences, and technology. At this point, we must fall back on our knowledge of physical limits and laws, and fundamental human needs and aspirations, in order to describe the world. Over this sort of term, it is useless to even attempt to describe (model) chains of causalities and back-casting becomes the only possible approach. Taking into account physical limits and laws on the one hand, and the fundamentals of human needs and aspirations on the other, it examines what changes – to socio-economic structures, value systems and preferences, and technology – would be likely to take the energy system to a desirable state at some date in the future.

The figure below syntheses these developments.

**Figure 1.1: Time and uncertainty in forward-looking methodologies**

<table>
<thead>
<tr>
<th>Time</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short term</td>
<td>Prediction</td>
</tr>
<tr>
<td>Medium term</td>
<td>Forecasting, Extrapolation, Optimisation</td>
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<tr>
<td>Long term</td>
<td>Foresight, Exploratory scenarios, optimisation</td>
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<tr>
<td>Very long term</td>
<td>Back-casting scenarios</td>
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</tbody>
</table>

1.1.2 | **Heritage and degrees of freedom:** accounting for temporalities over one century

Most of today’s equipment and infrastructure will no longer exist in 2100

We know that over the years, equipment and infrastructure progressively disappears or is replaced: rather quickly in the case of end-user appliances like refrigerators and cars (7-15 years), more slowly for industrial facilities (up to 40-50 years) and much more slowly for buildings and transport infrastructure (up to 100 years, or even more). We can therefore be sure that a very large part of today’s equipment and infrastructure will not be around in 2100.

From a forecasting/back-casting viewpoint, this means that existing equipment and infrastructure will have little influence on the situation in 2100, as this will be largely determined by what will be designed, produced and implemented in the decades to come.
In the field of energy, it takes decades for large technical and societal systems to change

History shows us how systems grow and change. The long lead times that characterise the energy system can be illustrated by a sketch of the development of the electricity system.

The launch of the electricity system is connected to a number of key discoveries such as Faraday’s investigation into induction in 1830 and the introduction of the dynamo-electric generator by Siemens in 1866. Such findings and inventions formed the basis for later systems. Edison should nevertheless be recognised as the key inventor, not only for inventing one of the system’s most fundamental components, the light bulb, but also for combining all the individual components of a system, from generator up to light bulb, and for inventing the necessary support systems, like electricity meters [7]. His major achievement, however, was the introduction of the light bulb, which ushered in a new wave of industrial R&D. In 1882 Edison launched his first electric utility in Pearl Street. In the first stage, 400 lamps were installed and the entire grid covered no more than one square mile (Hughes, 1983).

In Berlin, it took roughly four decades for more than 50% of households to be connected to the electricity grid.

The long lead time is mainly explained by the fact that lighting in the city was already being supplied by another system, powered by gas. The gas distribution network was already present in large cities at the beginning of the 19th century, and had spread to smaller towns by the time electricity came along. Lighting with city gas was considerably cheaper than electric light. But electric light offered other advantages: no emissions, less heat, easier handling, greater safety and an image of modernity. But only a tiny minority were willing and able to pay the higher price for these advantages. Electric light was installed in opera houses and theatres, fashionable hotels and restaurants, and banks. These few customers helped bring down the cost of electric lighting. Meanwhile, electricity found new applications in mechanical power: driving electric motors to replace steam engines and belt traction, and in public transport. Streetcars were powered by electricity. The progressive uptake and learning process led to a massive introduction, by which time electric light became cost competitive with gas light.

This example is typical for technological changes. A new invention finds application only in niche markets. These applications then initiate a learning process, which in the end leads to full competitiveness of the new product.

Policies and measures, too, may take decades to be designed, socially accepted and implemented.

Today’s energy system will progress towards sustainability through the direct combination of market forces and policies and measures aimed at sustainability. Some policies and measures, in particular those that seek to change consumption patterns, lifestyle or land-use, may take decades to be designed and accepted. Some, such as in R&D, may be implemented rapidly but not see results for years.

Looking at the turn of the century from a back-casting perspective suggests that a transition to a desirable and feasible future in 2100 will need to take into account both the time lags of changes in technologies, lifestyles, and socio-economic organisation, and the time lags of the policies and measures necessary to induce these changes.

1.2 | Chapter 2

Assessing fundamentals of needs over 100 years

VLEEM \(^{(8)}\) [Very Long Term Energy Environment Modelling] was a European research project, co-sponsored by the European Commission (DG-RTD) and ADEME (French Agency for Environment and Energy Management), and carried out from 2001 to 2005. All the developments below are based on the findings of the VLEEM.

To some extent, the VLEEM project proved that it is possible to provide a quantitative assessment of energy systems over the very long term, and still give adequate consideration to demographic, macro-economic, socio-cultural and technology elements. The VLEEM model also introduced new parameters to long-term modelling, including the level of information in societies and the concept of time budgets.

1.2.1 | Addressing the needs of energy services

Need for energy services: a necessary concept for very long term energy analysis

Energy products are used exclusively for the service that they provide, such as comfort, food or steam.

Until now, this has been captured in long-term energy-demand models [mostly techno-economic] by describing “energy end-uses” like space heating or cooking. But for time horizons over 30-40 years, this presents certain challenges. In the case of space heating, for example, indoor comfort has been assessed up until now by the demand for space heating in cold winter countries. This makes sense when considering today’s buildings, but not for passive solar buildings or zero energy buildings, which may become

\(^{(8)}\) Very Long Term Energy Environment Model. www.VLEEM.org
standard in the distant future. In such buildings, thermal comfort in winter is provided naturally by solar radiation and the architecture, not by the injection of heat from commercial energy carriers. Instead, new services will emerge, such as ventilation or hygrometry control (to regulate atmospheric humidity), that may require grid electricity.

The same goes for cooking. Food preparation is becoming increasingly industrialised and eating out is replacing home cooking, while new domestic services related to storing frozen food and microwave heating are emerging. Modelling the end-use “cooking” bears a decreasing relation to the reality of energy services related to food and eating, both at home and elsewhere.

In general, human needs attached to energy end-uses are deeply determined by the available technologies. Private cars, for example, respond to transport needs that would not exist without cars. Looking at needs over the very long term requires an examination of issues more closely related to people’s lifestyle and behaviour, independently of production systems and energy end-uses. Instead of referring to “energy end-uses”, VLEEM preferred “need for energy services” attached to “socio-cultural functions”.

It identified five basic socio-cultural functions:
- “food and eating”;
- “shelter and lodging”;
- “working for money”;
- “self fulfilment, social and individual”;
- “mobility”.

The need for energy services is expressed in a manner specific to the energy service: for example, food conservation is an energy service attached to the function “food-eating” and the need for food conservation means the permanent storage volume for conservation needed by a household. The need for energy services attached to a socio-cultural function includes both the need expressed directly by individuals and that of the production system.

Need for energy services is closely connected with time budgets: either directly (for example, the less time people spend in the food-eating function, the more diversified the energy services and the more intensive the needs) or indirectly (for example, the more time someone spends working for money, the greater their affluence, larger their house and the more diversified their indoor services).

Need for energy services must not be confused with energy demand

The need for energy services can be satisfied with a combination of specific energy products and specific equipment, both of them part of the same technological package.

In very general terms, it can be said that any energy product could satisfy any need for energy services: it is just efficiency and cost that will vary.

Efficiency depends on the exergy of the energy product (i.e. amount of work likely to be produced by 1 GJ for example) compared to the exergy demand for the energy service (very low in case of space heating, very high for computers, for example): the less efficient the energy product, the more is needed.

Cost depends on physical parameters of supply, such as production unit size, requirement for transport and distribution networks, storage requirements etc. The more centralised the production, the greater the economies of scale for production, but the higher the transport and distribution costs. The more decentralised the production, the greater the economies of series, and the lower the transport/distribution costs.

Three criteria can be used to specify the need for energy services of future energy systems:
- the spatial distribution of needs;
- the power requirement at the place where the individual needs are expressed;
- the exergy level of the service.
Need for energy services thus results in demand for useful energy. Meanwhile, the quantity (GJ) and quality of useful energy required depend on the physical and technological context. For example, food conservation could mean refrigeration, freezing or any other conservation technology, and the amount of useful energy needed for a certain quantity of food depends on the technology used.

In VLEEM, the useful energy demand attached to the need for energy services was quantified first on the basis of the current technology paradigm, while taking account of technical progress within the paradigm. But, as shown by the case of passive or zero energy houses, the demand for useful energy associated with the same needs can change dramatically with specific developments in technology. Both the useful energy demand and, to an even greater extent, the final energy demand, may evolve quite differently compared to the need for energy services as a result of technological change.

1.2.2 | Demography, urbanisation and human capital

The need for energy services is driven by two basic demographic influences:
- A direct influence: the more people, the greater the need;
- An indirect influence: the more affluence, the more energy services per capita.

The need is also driven by people’s behaviour, itself also a matter of demographic structure (age structure, household structure) and of time use.

The direct influence of population on the need for energy services is straightforward: more people, more need. The indirect influence due to affluence requires some explanation. The VLEEM model assumes that economic development occurs over the very long term as a result of demography and the “human factor”. In this model, the development of labour productivity over the very long term plays a key role.

Labour productivity depends on technological development, the structures of production and skills. In VLEEM, all these are related to the information incorporated in technologies and organisations, the ability of technologies to master information and to education. Ultimately, information mastering and related progress in technologies and organisation are also driven by education. Therefore, in VLEEM, labour productivity is considered to be driven over the very long term by information, which in turn is driven by education. This relationship is formalised in an indicator designed to capture the information level in a society, which is calculated according to the rates of access to primary, secondary and tertiary education. Labour productivity is correlated to this indicator.

The "labour force” and “information” are the only production factors considered useful for the very long term studied by VLEEM. The working population and their level of information are what produces wealth. The composition of the working population depends on the volume and age structure of the population; their level of information is a direct consequence of the extent to which they have benefited from the education system.

The labour force is expressed and measured as the product of three components: the active population (i.e. population likely and willing to work), share of the active population actually at work and time budget for paid work (i.e. time that each person spends working for money in one year).

The opportunity to accumulate or convert “informed labour” for capital building depends on how wealth is distributed, and in particular the share that benefits categories of people who are no longer productive and who are simply consumers (mostly retired people). Again the age structure of the population appears to be a main determinant.
Information plays a further role in relation to the need for energy services: it drives the technical specifications of goods and services consumed by individuals and by the production system, which in turn determine the need for energy services.

Demography and migration over the very long term

Beyond its key role in economic development, and so for sustainability, demography raises questions concerning the social aspects of sustainability, such as, for example, multiracial, multicultural and intergenerational coexistence.

According to E. Todd [1], there is an almost irreversible movement worldwide for women to continue their progression towards equal access to education, wages and jobs. At the same time, fertility rates will fall in regions which are currently most prolific, creating the so-called “demographic transition”.

Recent observations show that fertility might start rising again in regions where the demographic transition is completed, such as Northern and Western Europe, where it is currently very low. This would depend directly on welfare provision, driven by the need to meet pension needs of an ageing population, a phenomenon that can be observed in Scandinavian countries.

The question is whether very long term stability of the global population is a pre-condition for sustainability, or if fluctuations in fertility rates and population are compatible with sustainability over the very long range, putting aside their tendency to cause disruption within, and migrations between, world regions.

A growth in the ageing population is to be expected in all regions. The increasing burden on the economy that results from this shift may prompt an appeal for young workers from other regions where the demographic transition is not so advanced. Today, western industrial ageing societies are looking for young migrant workers from Africa, the Middle East, Far East and Central and South America. These workers are well qualified (better informed) and attracted by high salaries in industrial societies. To a certain extent, such migration slows down economic development in the source regions (because it results in a lack of “human capital”). But it might also accelerate their economic development if the workers return funds or/and business opportunities to where they came from.

The question is whether such migration is likely to increase the gap between rich and poor, or on the contrary contribute to economic convergence through the transfer of knowledge and funds.

Western industrialised countries welcome some types of migration, but not all. The European policy debate about “Fortress Europe”, the explicitly racial policies of some European political parties and the question of illegal immigration show that migration can exceed acceptable levels and create social problems which cannot be compensated for by economic benefits.

The question is whether a threshold exists beyond which either social consensus no longer exists, creating unrest that impedes economic development, or apartheid-like policies are adopted, disrupting international relations and trade.

A complex issue, usually left aside in future energy studies

Most future-looking studies in the energy field point out the importance of demographics, but do not account for it in their quantitative evaluations: GDP is supposed to account for everything, including demographic influence.

This is due to the complexity of the demographic issue, and the extreme difficulty of formalising the links between demography and economic development with any accuracy.

Most international future-looking studies use UN population forecasts, in particular assuming that the world population will stabilise at around

8 billion people by 2050, with fertility rates stabilising at around 2.1 children per woman, independently of economic development expectations.

This is one [optimistic] scenario, but not the only one that should be considered. It says nothing about macro-economic consequences, about which world regions the global population will be living in, or the consequences for the number and structure of households.

Inconsistencies between demographic and macro-economic projections over one century would lead to a meaningless projection, in which an evaluation of the need for energy services would be similarly meaningless, the description of the energy system able to meet this need in a sustainable way would be wrong or simply impossible, and the messages to decision makers totally misleading.

The VLEEM study shows how it established its demographic projections for the end of the century as well as how it took account of the interactions with macro-economic projections. Basic assumptions [about fertility, mortality and migration] are limited within boundaries alongside economic and social dimensions of sustainability. The VLEEM study does not propose criteria for these dimensions, but provides indicators from which the reader can judge how sustainable [from an economic and social perspective] society will be up to 2100.

There was no attempt to substitute existing demographic models, such as those used by the UN, but simply to bring consistency to the demography-related drivers of the need for energy services, such as age, household structure, active population and education.

Population growth

The study’s Mid-Pop scenario is in line with the “Medium variant” of UN projections until 2050 as regards fertility and mortality, and shows the so-called “demographic transition” completed by 2050. It assumes a continuous decrease in mortality throughout the world, a rebound of fertility rates in industrialised regions after 2050 up to 2.1, and a halt to the decline in the fertility rate at around 2.1 in developing regions after 2050.

The world population is therefore expected to peak around 8.7 billion in 2050 and then slowly decrease, to 8.2 billion in 2100.

Sub-Saharan Africa is expected to experience the fastest population growth: its share in the world population would increase from 11% (2000) to 21% (2100). South Asia’s population is also expected to grow faster than the world population, increasing from a 22% share to 24%, whereas the Chinese population would fall from 21% to 13%, Europe from 10% to 6% and CIS from 5% to 2%. Shares for other regions are expected to remain more or less stable.

These projections take account of migrations between world regions, similarly to what the UN expects in the “Medium variant”.

Figure 1.2: Evolution and distribution of the world population by region
Population structure by age

Age is also a driver of the need for energy services, because of its relation with time-budgets (older people no longer work for money) and with health. VLEEM thus looks at the population in groups defined partly in relation to age. Behaviour and consumption patterns are assumed to change marginally with time within one particular group, but to change drastically from one group to another. The change in the structure of the population according to group is likely, therefore, to have a significant impact on the need for energy services up to 2100.

In the Mid-Pop scenario, an important consequence of the demographic transition and the decline in mortality is a growth in the ageing population throughout the world. The share of the world population over 75 increases from 2% in 2000 to 14% in 2100, and the share of those over 50 from 18% to 42%. This is most marked in developing countries, particularly in South Asia and China, where the share of over-50s rises from 18% to 43% and from 14% to 44% respectively. In industrialised countries, where the share of older people is already high in 2000, the phenomenon is less pronounced: the proportion of people over 50 increases "only" from about 30% to 42% between 2000 and 2100.

**Figure 1.3: Distribution of the population by class of age**

Household structure

Individual needs for energy services depends on the type and size of the household in which they live: the energy necessary to ensure a certain comfort in temperature is roughly the same if there are two or three people living in the house, but there is a scale effect on on the individual energy requirement. The structure of households according to size is thus also a driver for energy services that must be considered.

In the Mid-Pop scenario, in parallel to the ageing population, there is an ageing of households, as expressed by the age of the head of the household. The share of world households whose head is over 75 years would increase from 5% in 2000 to 22% in 2100 and those whose head is older than 50 would increase from 30% to 46%.

**Figure 1.4: Distribution of the households according to age of head of household**

This change in the age structure of households has a deep impact on the number, size and structure of households. Most households in industrialised countries with a head older than 50 years are either one or two person households. In developing countries, many households where the head is over 50 are still large. This is expected to shift, with the demographic transition, the development of education and the release of housing constraints, towards the model of industrialised countries. The development of education and the release of housing constraints will in turn boost the number of one-person and mono-parental households.
Altogether, the proportion of one-person households is expected to increase from 15% to 31% between 2000 and 2100, and that of households with two persons from 22% to 32%. The share of households with more than two people would fall from 63% to 36% across the world.

**Average size of households**

The change in household structure will result in a major decline in the number of individuals per household: from 3.7 (2000) to 2.4 people per household in 2100 for the world. This trend will affect, in particular, Sub-Saharan Africa (from 5.2 to 2.5), North Africa and the Middle East (from 5 to 2.4), and South Asia (4.9 to 2.4).

*Figure 1.5: Number of person per household (2000-2100)*

Energy consumption patterns are usually very different in urban and rural areas, in particular in developing countries: energy supply is more available in urban areas, urban lifestyles are much more energy consumptive (i.e. daily transport, the concept of comfort, household appliances, financial resources,…). A city dweller can consume up to 10 times as much as someone living in a rural area, on average, in the same country. The same applies, in a less pronounced way, between urban and suburban areas in developing countries: the behaviour and consumption patterns of people migrating from the countryside to the city, or from abroad, differ significantly from those of urban people.

Energy supply issues are also markedly different in rural and urban areas, because of the much lower spatial density of energy consumption in rural areas, which affects the cost-effectiveness of distribution networks (electricity or gas today, hydrogen tomorrow).

The distribution of the population among urban, suburban and rural areas is thus also a major driver of the need for energy services.

In the Mid-Pop scenario, along with an increase in the world population, there is expected to be a strong movement of people from rural to urban areas, due firstly to the decrease in agriculture land, secondly to the industrialisation of agriculture (fewer and fewer people can work and be accommodated per km² of agricultural land). This global phenomena is expected to result in the global rate of urbanisation increasing from 47% in 2000 to 75% in 2100, with the most drastic evolutions in Sub-Saharan Africa, China and Other Asia.

*Figure 1.6: Urbanisation rate (2000-2100)*
Education

The level of information in society is captured with an indicator based on enrolment ratios of the children in primary, secondary and tertiary school.\(^{(10)}\)

Enrolment ratios are strongly dependent on a country’s wealth, for two reasons:
- the cost of education, either for the taxpayer or for families with children, increases with the level of education, while the ability to pay depends on the average affluence of the population;
- the affluence of the family determines whether the children are sent to school, or used for family labour or paid labour (even where education is paid by the taxpayer).

Countries with the same overall affluence (GDP/cap) can nevertheless experience very different levels of school attendance, according to education and cultural policies, in particular regarding gender equality.

In the Mid-Pop scenario, we assume a certain convergence in cultural values, which means that non-economic obstacles to education are progressively removed. Enrolment ratios become determined by wealth alone, in line with what has already taken place in industrialised countries. Therefore, the situation for 2100 following world economic development \(^{(11)}\) is as follows: 100% of those aged 0-25 have been enrolled in primary and secondary school in all world regions, while enrolment rates in tertiary education range from about 70% for the industrialised countries of today (with a peak of 80% in North America), to about 50% for the other regions, with Sub-Saharan Africa at 42%.

![Figure 1.7: Enrolment of the young in tertiary education, (2000-2100)](image)

Information and productivity

The range of information levels across the world in 2000 was between 1.5 and 3 (with level 1 corresponding to a hypothetical situation where 100% of the population goes to primary school, but where secondary and tertiary education do not exist; the maximum is level 6, where 100% of children are educated to tertiary level).

In the Mid-Pop scenario, educational progress results in a steady increase in the information level everywhere in the world. Today’s industrialised countries, which have a higher information index for the year 2000, still have better levels of information in 2100. The range of information level in the world in 2100 is between 3 and 5.

As shown by former econometric analysis\(^{(12)}\), the information level calculated in VLEEM is strongly correlated to labour productivity (expressed by GDP per working hour). Two major interpretations can be drawn from the historical correlations:
- a geometric progression of both labour productivity and information level over a very long time period (interpretation based on the assumptions that cross-country analysis can substitute for unavailable very long term time series);

\(^{(10)}\) For further information, see the Annex 1 of the Final report VLEEM 1, available at Very Long Term Energy Environment Model, www.VLEEM.org

\(^{(11)}\) The world economic development is not assumed, but result from several forces, among which information (i.e. education in the past).

\(^{(12)}\) Final report VLEEM 1, Annex 1, available at Very Long Term Energy Environment Model, www.VLEEM.org
Activity

The activity level of individuals measures their participation in the labour market, either as employees or as independent producers. It is usually recorded in statistics according to gender and age. Different countries attach varying meanings to activity levels in their population: for some, it will refer only to people with a paid job or listed in official unemployment records; for others it accounts for almost everybody in an age category.

The activity level of households is determined by the structure of households and the participation of household members in the labour market.

In most situations, the heads of urban households below retirement age are considered to be active (although this might not be the case in rural areas where agriculture is still mainly a subsistence activity).

The labour market participation of the second adult in the household below retirement age (in most cases a woman), varies according to country, and bears no clear relation to level of development (since it depends on cultural values as well as social and economic policy).

The participation of children in the labour market is determined by the enrolment of children in school, and therefore by information level: the higher the information level of a society, the longer children spend in the education system, and the later they undertake paid work.

In the Mid-Pop scenario, we assume that a double convergence will occur in this area:
- the retirement age will become similar everywhere, to around 65;
- the participation of the second adult of the household in the labour market will peak at around 70% (or 85% on average for all adults below 65).
1.2.3.1 | Time-budgets, gender inequality, cultural diversity and energy systems in the very long term, according to VLEEM

The “human capital” expressed and measured in VLEEM involves both genders. Girls’ access to primary education will determine the information level of the economy (and average labour productivity) for almost 50 years, while women’s access to paid work determines the boundaries of the active population and labour force. The two combined determine a region’s potential economic growth over the very long term, and thus also individual wealth. At the same time, the more educated the women, the fewer children they have, and the smaller the future population. Population volume and structure, individual wealth and the number and make-up of households in 2050 and 2100 – which are the main determinants of the need for energy services – are thus, according to VLEEM, strongly connected to gender equity.

The time budget of individuals and households is driven by three major influences:\(^{(13)}:\)
- individual willingness to replace time with goods and equipment for domestic functions (mainly food and eating) whenever possible;
- individual willingness to replace work with leisure (when the value of leisure time, less the cost of related leisure goods and services, exceeds earnings from work);
- social willingness to increase the time allocated to education for future generations in order to improve the information level of society.

Achieving sustainability assumes that a trade-off is made in time budgeting between individual and social aspirations on the one side, and macro-economic constraints related to increasing wealth on the other. As suggested above, this trade-off is strongly dependent on gender equity in a society.

The need for energy services up to 2100 is also driven significantly, according to VLEEM, by developments in time budget structures, and through individual wealth and information.

In VLEEM, cultural diversity is captured by regional parameters that cover time budget structures, the role of gender in education and access to paid work, fertility rates and the elasticity of the need for energy services to wealth or to time budgets. Projections of the need for energy services are strongly related to these parameters.

Questions about cultural models

Attitudes to change, cultural values and mentalities may impact regional discrepancies around the world. Historical empires – Roman or Chinese, British, French, Russian – as well as the current, American, one, all support the idea that empires can impose long-lasting cultural and linguistic convergence, on a regional basis if not worldwide.

Global civilisations and cultural models are in perpetual dialectic between expansionism and local vernacular resistance. In this respect, the 21st century can be seen as hesitating between two directions, neither of which is incompatible with sustainability:

- a unipolar or bipolar world where the United States continues to dominate, to be joined by China as another hyper-power within the century;
- a multipolar world, constituted by strengthened regional blocs such as the European Union, Peoples’ Republic of China, ASEAN countries, Brasil Mercosur South-America countries, Egypt Middle-East Arabic Muslim countries, or other emerging regional blocs.

Until recently, the US showed most of the characteristics of a classical empire[^14], where its citizens’ well-being is guaranteed by organising and securing huge economic and monetary transfers from the rest of the world to the US (the trade balance deficit is an appropriate measurement of this transfer). Us culture expands on a global level through elites and ICTs, and growing numbers of inhabitants in other world regions adopt US lifestyle standards. In the meantime, regional power blocs such the European Union and China today, probably ASEAN and MERCOSUR tomorrow, and India, are emerging and strengthening. These blocs are build around common socio-political and cultural traditions, the free movement of people, goods and services in a single market, monetary union and communication paths. The stronger they become, the more likely they are to balance US influence, which may result either in the emergence of a bipolar world or else a more diversified multipolar world, with more diversified lifestyles[^15].

In response to the social and cultural challenges of “Western”-style development, a number of new ideologies have sprung up that place a greater emphasis on spiritual, sharing and collective values, in opposition to consumption, money-orientation and individualism. This sort of ideology could result in very different lifestyle to that typical to industrialised countries. At the same time, a section of the population will still adopt and have the means to purchase the goods and services proposed by “Western” technology and fashion.

How might these cultural models affect our representation of lifestyle and aspiration? For this element, VLEEM was strongly influenced by the Western European cultural model, in particular when assuming that development is accompanied by less time spent working and more time spent in self-fulfilment. This tendency observed in Europe is already in conflict with the United States’ pension system due to the required profitability of shares on European stock markets. This pressure on Western salaries is reinforced by competition with the developing world.

[^14]: On this matter:
- Meyer, L. [August 1999], The power of one, Reforma, Mexico.
- Mittal, A. [summer 2003], The fire on open markets - Strategy of an Empire, Backgrounder newsletter, Food First.

1.2.3.2 | Visions for behaviour and lifestyle up to 2100

Most data used in the development below has been taken from the MTUS database [14].

Time spent in the food function [17]

As shown in the figure below, there are large discrepancies among world regions today for time spent in the “food function”. These reflect different development levels, household structure and culture. If we express development level with information level (because of the strong link with labour productivity), we can classify world regions in three groups:

- a first group with a small information level and a high time budget for the food function: Sub-Saharan Africa, South Asia, China and Other Asia (about 6 hours per day);
- a second group, also with a small information level, but a lower time budget for the food function: North Africa and Middle East, Latin America (less than 4 hours per day);
- a last group with high information levels and low time budget for the food function [Europe, OECD Asia, North America and CIS; less than 3 hours per day].

In the Mid-Pop scenario, we assume that globalisation leads to some harmonisation in lifestyles and consumption patterns around the world, driven by more economically advanced countries. One result is that along with improvements in information level in less developed countries, time spent in the food function tends to converge to the situation of more industrialised countries today: around 3 hours per day. For more industrialised and “informed” regions, time spent in this function is expected to fall even more, to approximately 2.5 hours per day.

Time used in the shelter function [18]

There are also discrepancies in time spent in the shelter function. These seem to have two main origins: habits [19] and household structure according to the age of the head of household. There is no direct link with development level.

The world regions can be classified into three groups:

- South Asia, China, Other Asia, CIS and SSAf, with a high time budget for shelter (about 13.5 hours per day);
- Latin America, North Africa and Middle East, OECD Asia: with a medium time budget, about 12 hours per day;
- Europe and North America, with a low time budget, about 10.5 hours per day.

[19] Differences in habits reflect in fact two things, which cannot be really separated out: actual differences in the time spent for sleeping, hygien, housework, and differences in the definitions of the component of the function, according to national surveys (statistical discrepancies).
In the Mid-Pop scenario, we have assumed that the “habits” component will not change over time: for the same class of household (age of the head), the time budget for this function is assumed to remain constant. But household structure is expected to change (see above), and this will result across the board in an increase in the average time budget for this function, to a greater or lesser level depending on the strength of the demographic transition.

Time spent working for money

The time spent for working for money is the result of three basic influences:
- the activity level of the population and participation in paid work;
- labour regulations: hours/day, holidays, retirement;
- the level of education.

This time is more or less productive, according to the information level of a country, employment policy and the statistical meaning attached to activity and jobs.

There is, therefore, no clear relation between time spent for working for money and the level of development. Nevertheless, world regions can be roughly classified into two groups (with the exception of South Asia):
- regions with a high information level, where people spend between 1.5 and 2 hours per day for working for money (life average);
- regions with a low information level, where people spend more time at work (for money), between 2.5 to 3 hours per day.

In the Mid-Pop scenario, we have considered three basic assumptions which have direct consequences for the time budget spent working for money:

a) education is supposed to develop everywhere, to a model similar to that of industrialised countries, with a similar impact on productivity and economic growth (although it reduces the time spent in paid work);

b) labour regulations tend to progressively harmonise throughout the world due to globalisation, resulting in reducing the time budget for paid jobs;

c) restrictions to women’s access to paid work are progressively removed.

These assumptions lead to some convergence in the overall working hours per capita per year to about 500 (with similar demographic structure), and the overall working hours per employee per year to about 1,500.

At present, we have two groups of developing regions:
- Sub Saharan Africa, China and Other Asia, where overall working hours today are less than 500 hours per capita per year, and less than 1,500 hours per employee per year (a result of high activity rate of the population, low utilisation rate of employed people and demographic structure): these regions are assumed to increase to 500 hours per capita per year or 1,500 hours per employee per year with the rise in information level;
- Latin America, North Africa and the Middle East, where working hours today are more than 500 hours per capita per year and 1,500 hours per employee per year (a result of low activity rate of the population, high utilisation rate of employed people and demographic structure): these regions are assumed to decrease to 500 hours per capita per year or 1,500 hours per employee per year with the rise of the information index.

One question remains, which has been partially solved in the Mid-Pop scenario: the trade off between getting more money by more working hours and getting more time for self-fulfilment. This question has been debated from a theoretical point of view since the Sixties, without reaching a consensus. The two competing models seem

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World and European Energy and Environment Transition Outlook – WETO-T

VLEEM assumes that the time available for self fulfilment is the “swing time budget”, or remainder, that makes for a total 24 hours a day. As such, it is determined by the evolution of the time budget for other functions (above), the time budget for working for money and the time budget for transport (kept constant at one hour a day, according to Zahavi’s conjecture).

The result of the assumptions above is a tremendous increase in the time for self fulfilment in the developing world, and a slight increase in the industrialised world.

Figure 1.12: Time use for self fulfilment and information (2000–2100)

Time budget structures

On average for the whole world, VLEEM’s mid-pop scenario shows a decline in time budgets for food, from 22% in 2000 to 13% in 2100, and working for money, from 10% to 7%; an increase in time budgets for self-fulfilment from 16% in 2000 to 27% in 2100, and a stabilisation of the time budget for shelter (53%).

Time used in the self-fulfilment function

Large discrepancies exist throughout the world when it comes to self-fulfilment, according to the level of development.

Two groups of regions can be identified:

- world regions with a high information index, where people spend between six and eight hours per day in self fulfilment (mostly industrialised countries);
- world regions with a low information index, where people spend 2 to 4 hours per day in self fulfilment.

Figure 1.11: Time use for labour and information (2000–2100)

Time budget structures

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But taken over the very long term (100 years), this can be assimilated to the capitalisation of human capital over previous years.

The number of working hours is a product of the size of the working, active population and the time they spend at work. The active population is defined according to two boundaries: the level of education (when young people leave school or university), and retirement practice (when workers retire). In practice, the size of the working population also depends on socio-cultural factors (namely female participation) and unemployment rates (appropriate size of labour force to the demand for physical capital and goods and services).

The amount of time spent at work depends directly on time use structure, on the socio-cultural model and information level (see above).

Questions regarding the measurement of welfare and social inequity

A comprehensive tool to measure welfare and inequity is already available, reported in the annual report of UN PNUD on human development, the “HDI”.

“’The Human Development Indicator (HDI) measures the average level reached by a given country according to three essential criteria of human development: longevity, access to knowledge and life level. Those three aspects are respectively based on the life expectancy, the level of instruction [adults alphabetization ratio combined with access to primary, secondary and superior schooling ratios] and income per inhabitant, corrected and expressed in purchasing power parity (PPP)”[23].

Linking welfare and sustainability throughout HDI figures then can respond to the need of an operational concept that integrates a social and environmental element, as well as a cultural, political and economical one.

HDI allows for ranking to be defined. Comparing HDI levels provides an insight into the link between a certain social cultural and political option and the human benefit. This raises the question of what consequences a significant and persistent HDI gap might have for the socio-economic conditions for sustainability. Two aspects should be considered, internal and external.

An internal HDI gap within each world region, considered relatively homogenous from a linguistic and cultural perspective: the higher the wealth, the smaller the HDI gap within the region, the more settled the social situation.

An external gap between world regions: the smaller the gap in HDI between world regions, the calmer the international relations, and more fluid the economic and financial flows among regions.

The last century shows that there is no immediate link between social inequality and social instability. But there is growing evidence that a decline in public mental and physical health, and self-inflicted harm (consumption of drugs, suicide, risky behaviour) as well as violence towards others (bombings, terrorist suicides, vandalism) are steadily increasing. In principle, democratic systems are able to absorb periodical social turmoil peacefully. But violence may lead such systems to seek protection through the reduction and suppression of civil and human rights, paving the way for totalitarian-like regimes.

In terms of the evolution of relative levels of HDI, for sustainability purposes, it can be assumed that existing gaps across the world will not widen.

In VLEEM, wealth refers not (just) to GDP, but to human capital. Although there is no formal social link, the concept is closer to the HDI than GDP alone.

Production and economic development

A distinction should be made between economic production and wealth, the difference being a matter of purchasing power on the world market (just as the difference between GDP in US$ expressed at market exchange rates and at purchasing power parity). In VLEEM, economic production primarily and wealth secondly are driven by the number of working hours and productivity per labour hour. The translation of economic production into wealth is itself dependent on the information indicator.

When comparing economic situations of regions and countries in 2000, it appears that discrepancies in productivity per working hour (measured by the GDP per working hour at purchasing power parity and the labour hours as calculated in VLEEM) do not properly reflect the variation in information level. This apparent contradiction comes from the fact that the global availability of human capital is significantly higher than what is actually required to run existing production facilities (physical capital) and related services, given society’s current information level. The relative ratio between the two quantities measures the rate of actual use of production potential of the country/region.

In the very long term, the evolution of this ratio is driven mostly by the fluidity of the financial capital across the world: the lower the ratio, the higher the investment opportunities.

VLEEM assumed, in the first instance, that global savings will be sufficient at any time to finance the global investment required by growth in production arising from the two drivers outlined above.

In the Mid-Pop scenario, it is also assumed that existing barriers to the movement of financial capital will be progressively removed in an increasingly peaceful and cooperative world. As a consequence, the rate of use of production potential will tend to increase everywhere up to a technical limit around 95% (assuming 5% structural unemployment of human capital), [see figure 1.14].

The consequence of all the assumptions above is a global convergence in economic development as measured by the production per capita (proxy with the GDP per capita at purchasing power parity).
This convergence is strong in relative terms, but the absolute difference in per capita production continues to increase between more and less advanced countries.

**Figure 1.14: Index of use of human capital (2000-2100)**

![Index of use of human capital graph](image)

**Figure 1.15: Economic development (2000-2010)**

![Economic development graph](image)

*EDi, Economic Development Index, is constructed on the basis of GDP per capita at purchasing power parity at base year.*

From economic development to wealth and welfare

The growth in economic production per capita contributes to an increase in individual affluence, country wealth and general welfare in that country. This is obviously true within a country with no external trade: the more is produced, the more opportunity people have to consume, and the more they will consume. But it is also true at a global level, through another mechanism: the greater a country’s production, the closer the value of its currency on the financial market to its purchasing power on the world market. For example, in a country with a low GDP/capita (expressed in i.e. EUR at current exchange rate), an average worker can buy two shirts in his country with a day’s salary. If he travels to the US and changes his salary into US$, he will be able to buy only one shirt. If his country then experiences several years of strong economic development compared to the US, he will be able to buy 10 shirts with one day’s salary in his own country (consumption level multiplied by five because of the production increase), but eight shirts in the US (and not five), because of an improvement in the exchange parity of his currency against the US$. He is five times richer in his own country, but eight times richer at the global level.

In the Mid-Pop scenario, where globalisation is assumed to be driving world economic development, differences in production growth rates compared to more industrialised countries (North America, Europe and OECD-Asia) result in a reduction of the gap between the exchange rate and the global purchasing power of currencies, and in even bigger differences in the growth rates of wealth and affluence (measured in the ability to purchase goods and services worldwide).
1.3 | Chapter 3

Need for energy services up to 2100

1.3.1 | Measuring the need for energy services

Energy services include such things as food conservation, indoor climate, individual modes of transport, etc. The need for the service is measured in specific units, such as volume of food to be conserved, dwellings to be heated or cooled, kilometres in individual modes of transport, etc.

To support the structural analysis of the need for energy services (which requires aggregation and comparability), and for modelling purposes, these needs have eventually to be expressed in the same unit (for instance PJ), for all years.

All energy service needs generate a demand for useful energy and a final energy demand. As explained above, the relation between the need for energy services and the related need for useful energy is determined by the prevailing technology paradigm.

Within the current technology paradigm, we can easily convert the need for energy services into need for useful energy. Should the technology paradigm change, however, the conversion would be much more complex.

VLEEM adopted two solutions to resolve this complexity:

a) for the structural analysis of the need for energy services, these are expressed in PJ using the conversion coefficients to useful energy at base year (2000), i.e. corresponding to today’s technology paradigm. This allows for the construction of matrices of energy services according to quality criteria (exergy, spatial density, unit power), which is the basic instrument for the structural analysis;

b) to support the dynamic analysis of the need for energy services (which requires homogeneity across time), the evolution of the need over time is captured with indexes based on specific units for each energy service.

In this chapter, all the graphs and comments below are based on the indexes. Aggregated figures are provided whenever necessary. The corresponding indexes are calculated combining both approaches.

1.3.2 | Food and eating

There are three main drivers to the need for energy services in the food function: time used carrying out that function, affluence and population. The less time the people spend in the function, the less time is devoted to cooking, the more household appliances they use, and the more food they eat that has been prepared outside the home. The wealthier they are, the more sophisticated their appliances, and the more diverse and elaborate the industrialised and ready-made food products they can buy.

Depending on the region’s climate and arable land, the food production system – from primary agriculture to ready-made dishes – may be unable to meet the food requirements of the region’s people, or it may produce more than enough. This explains the wide variability in the per-capita need for energy services related to food, even among regions with similar time use and affluence.

This observation does not contradict the statistical confirmation of the general relations between the need for energy services per capita on the one hand, and time use and affluence on the other, as shown in the figures below.

Doubling the need for energy services for food worldwide from 2000 to 2100

In the Mid-Pop scenario, it is assumed that the link observed today in industrialised countries between the need for energy services in the home, time use and affluence constitutes a reference towards which less developed countries will converge as they progress at an information level.

Similarly, it is assumed that the need for energy services in food production per unit of primary food product will change with affluence, in line with the experience of industrialised countries today.
The quantity of primary food products produced and processed are supposed to be determined entirely by the availability of arable land at the turn of the century (associated with the use of fertilisers and pesticides). Some regions of the world with low population density, like the CIS for instance, are thus considered to have large arable land surpluses (as compared to their domestic food requirement), which drive a steady increase in the need for energy services in the food production system (in particular because of climate change).

The need for energy services for food worldwide is expected to double from 2000 to 2100 in the Mid-Pop scenario, while the world population increases by a third. The range of needs of energy services per capita, which is between 4 and 7 today, would be from 5 to 9 in 2100, with the exception of the CIS, which would reach 14 (a huge country for a small population).

**Figure 1.16: Need for energy services for food and time budget (2000-2100)**

Growing importance for the food production system and high exergy requirement worldwide

As the need for energy services per capita evolves, so does the structure of these needs: with an increase in the level of information, there is a lesser need for energy services to cook food and an increased need for household appliances (for food preparation and conservation, and cleaning), as well as for food production, from agriculture to food processing. The needs of the food processing industry grow fastest. In industrialised countries today, the non-household need for energy services related to food (activities including farming and the agri-food industry) already represents the largest portion of total needs in the food function.

In 2100, the outside-the-home food need is calculated by VLEEM to represent roughly half the world’s total need, up from 30% in 2000. In the meantime, the need for energy services related to cooking food are expected to decrease significantly, by roughly one-third worldwide.

In Europe, where the food production system already accounts for 58% of total needs, the share of outside-the-home needs is expected to grow to 68%, while needs relating to cooking within the home will decline by 17% in absolute terms.

Because of this structural evolution, another change takes place alongside the overall per capita increase in need. Those that involve low exergy requirement (basically cleaning) increase moderately, while those involving high stationary exergy requirement (mechanical power, electrical power) increase rapidly, representing more than half the total needs almost everywhere in 2100 (compared to some 20% worldwide today). For the world as a whole, the total need for energy services corresponding to medium exergy requirement (medium temperature heat) is expected to decrease a little in absolute terms.

In Europe, the share of needs requiring high exergy would climb from 41% today to 52% in 2100, while the share of those requiring medium exergy would decline from 47% to 39%.

*ESI, Energy Services Index, is constructed on the basis of the useful energy requirement per capita at base year, with conventional end-use efficiencies.*
There are three main drivers for the need for energy services related to shelter: affluence, housing stock and population. The more affluent people are, the larger the dwelling per capita, and the better equipped the dwelling for comfort and amenities. The smaller the average size of household, the larger the housing stock, floor area and equipment per capita.

Climatic differences explain the huge gap in the need for energy services for shelter per capita between cold regions in the Northern hemisphere and warm regions in tropical areas, both sides of the equator: about 8 for OECD Asia, 12 for Europe, 16 for CIS and 21 for North America, against 0.6 to 2.8 in the developing world. In industrialised regions with both types of climate (the US or Japan, for instance, and to a lesser extent the EU), however, the difference between people’s needs is much smaller: they have needs of a different nature, but of similar magnitude.

Nearly tripling the need for energy services for shelter worldwide from 2000 to 2100

In the Mid-Pop scenario, it is assumed that less developed countries will converge towards the situation of industrialised countries today when it comes to the link between affluence and the need for energy services inside homes. This will occur alongside the country’s progress in information level, albeit at a different speed and with final levels depending on climatic conditions.

The need for energy services in construction per housing unit is determined by the techniques and materials used. These are assumed to harmonise worldwide before 2100.

The number of dwellings built and maintained is determined by the number of households in each living area – urban, suburban, rural – and by the replacement rate of the existing housing stock.
The need for energy services related to housing are calculated to almost triple worldwide from 2000 to 2100 in the Mid-Pop scenario, while the number of households would double. The range of needs for energy services per capita, which is between 0.6 and 21 today, would vary from 5 to 28 in 2100.

Figure 1.18: Need for energy services for shelter and economic development (2000-2100)

Thermal comfort drives need

Thermal comfort (space heating and cooling) is, and will remain, the main energy service need for housing. Representing 60% of the need in 2000, it will rise to 66% in 2100 at a global level. It is not expected to grow significantly in industrialised countries, where it is already well developed, so much as in the developing world (regardless of climate), where greater affluence and living standards are expected to drive a strong demand for thermal comfort appliances, central heating and air cooling.

In Europe, thermal comfort accounts today for 67% of the need for energy services in the shelter function; this share is expected to grow to 70% by 2100\(^\text{24}\).

After thermal comfort, sanitary comfort is also expected to rise everywhere, in particular in developing countries. Differences in climatic conditions will continue to explain large discrepancies in the need per capita: the warmer the average outdoor temperature, the less the need to heat water. The share of sanitary comfort in the total need for energy services related to shelter is expected to decrease, from 18% in 2000 to 12% in 2100: industrialised countries are already well equipped, and the increase in the developing world will be limited due to climatic conditions.

In Europe, sanitary comfort accounts today for 19% of the need for energy services for housing; this is expected to fall to 16% by 2100.

Lighting is the main component of the last group of energy services for the shelter function, along with cleaning appliances. Both are expected to experience a fast development, in particular in the developing world, due to the rise in affluence. In today’s industrialised countries, where household equipment is already very high, the impact of affluence is expected to be much weaker.

In Europe, household appliances and lighting account today for 9% of the need for energy services related to shelter; this share is expected to rise to 11% by 2100.

The share of housing construction and maintenance in the need for energy services, which is today around 11% worldwide, is expected to fall drastically by the end of the century, nearing 4%.

In Europe, this share is already quite low – 4% – and is expected to decline even further, to 2%.

\[^{24}\] Again, this does not mean that space heating will account for 70% of households energy demand: if passive housing is to develop in Europe, most of these comfort energy services will be supplied by solar radiation, re-use of internal heat sources and adequate insulation standards.
Towards a spatial densification of the need for energy services for shelter

The high density/low power needs are the main needs for shelter almost everywhere except China, where low density/low power account for more than half of total needs. As the main consequence of the urbanisation process expected everywhere, the share of high density needs is calculated to increase, from 61% of total needs in 2000 to 77% in 2100.

One of the most striking features of the need for energy services for shelter is their low unit power requirement: almost 90% of today’s needs today are of this type, and this is calculated to increase to 95% at the turn of the century. This means that a very high share could be supplied, now and in the distant future, with very diffuse energy sources or supplies.

The same remark can be made for Europe, where low density/low power needs are calculated to decrease in absolute terms from 2000 to 2100.

1.3.4 | Self-fulfilment

The fastest growth of the need for energy services worldwide from 2000 to 2100.

The need for energy services for self-fulfilment within the home[25] is calculated to grow 16-fold from 2000 to 2100 worldwide in the Mid-Pop scenario, driven mainly by changes in time-use, affluence and information level.

The more affluent people are, the better equipped their home for information, communication and indoor electronic leisure. The smaller the average size of household, the larger the dwelling equipment per capita. The more time available for self-fulfilment, the greater the use of domestic equipment.

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[25] The need for energy services for self-fulfilment outside the home (sports, cultural activities, visiting friends and relatives, tourism, etc.) are accounted for in the mobility function.
Information plays a double role: it drives down the share of time used for indoor activities related to self-fulfilment (the more time available, the more opportunity for outdoor activities), and it drives upwards the share of the time used with ICTs within indoor time-use (the higher the information level, the more availability of ICTs).

In all story-lines, it has been assumed that industrialisation and the marketing of goods and services related to information, communication and self-fulfilment will be the drivers for consumption in today’s industrialised countries for the whole of the next century. The reason for this is that using such goods and services for leisure is the only means likely to increase the utility of time spent in these activities at a level comparable with the value of time spent working for money (otherwise, there is no reason for people to look for more time for self-fulfilment and less time for working; see VLEEM 2 final report[^26], chapter 1, about the theoretical foundation of this assumption). This is also assumed to be the case for the developing world, but at a later stage in the century.

All needs for energy services for indoor self-fulfilment are high exergy needs (basically electricity), with low unit power: they could thus be supplied with electricity distributed via the grid or generated in-situ.

In the Mid-Pop scenario, we have assumed that the relationship observed today between the need for indoor energy services per hour of self-fulfilment, the information level and affluence can serve as a reference for all countries of the world, and for the whole century.

The need for energy services for self-fulfilment is calculated to increase worldwide by a factor of 16 from 2000 to 2100, while the population increases by just 36%.

The model simulates a very strong rise in time used for self-fulfilment in less-developed regions (from about 1.5-3.5 hours per day to about 5-7 hours per day on average) and a strong increase in energy needs in parallel with this.

For the most developed regions, the model simulates a slight increase in time spent in self-fulfilment (which was already high in 2000), but a strong rise in energy needs per capita (between a factor of 3 and 11, with 9 for Europe).

Figure 1.20: Energy needs for self fulfilment and time budget (2000-2100)

Figure 1.21: Energy needs for self fulfilment and information index (2000-2100)

1.3.5 Mobility

The three main drivers of the need for energy services for transport are affluence, transport infrastructure and organisation, and population. The more affluent the population, the greater the volume of private vehicles, the further and faster they can go, the more goods [including those of high value] can be transported, and the higher the

value of freight speed. Transport infrastructure and organisation determine both the spatial distribution of production activities worldwide and the urbanisation pattern on the one hand, and the relative competitiveness/attractiveness of competing transport modes on the other.

There are significant differences in transport infrastructure and organisation among industrialised countries today, and this explains current discrepancies in the need for energy services per capita for mobility among countries with a similar level of affluence. These differences have historical origins, linked with the country’s spatial dimension, population density, urbanisation pattern and history of the transport system.

More than quintupling the need for energy services for mobility worldwide up to 2100

In the Mid-Pop scenario, it is assumed that the relation observed today worldwide between the average speed of personal and freight movement and affluence constitutes a reference that will apply to all countries for the whole century. This basic assumption will be further discussed in Part 2 of the report.

The need for energy services for transport infrastructure production is determined by the passenger and freight traffic, in a relationship which is expected to harmonise worldwide before 2100.

The need for energy services for transport worldwide is expected to be multiplied by around five from 2000 to 2100 in the Mid-Pop scenario, while population grows by 36%. The range of per capita needs, which is between 0.6 and 23 MJ/cap today, would range from 10 to 33 in 2100. In Europe, the need for energy services per capita will almost double, from 7.7 today to 14 in 2100.

Passenger mobility

The time budget for mobility has been kept constant everywhere at roughly the same level: one hour on average, per person and per day. This assumption, which is based on Zahavi’s proposition[27], has been validated by a number of studies, although some doubt has arisen recently from an analysis of time spent in outdoor self-fulfilment activities [in particular tourism][28].

Assuming this time use constraint, however, implies that any increase in passenger mobility (km/capita/year) will be a direct consequence of an increase in average speed. Average speed is driven by affluence, through an elasticity which has proved to be fairly stable over time and is very similar from one country to another. Since the period in which this elasticity has been measured is entirely dominated by the road transport model, it should be noted that the value reflects the situation of this model, rather than a fundamental law of the mobility dynamics.
In particular, ongoing studies into “decoupling mobility from economic growth” suggest that an increase in speed could be “decoupled” to some extent from economic growth if the transport system were differently organised, and a similar accessibility could be provided at lower speeds within the overall time-use constraint.[29]

Since every transport mode has a critical speed for each type of trip (urban versus regional versus long distance), there is a global relationship between the average speed of passenger mobility, the mobility structure according to trip type, and the relative share of different transport modes for each trip type. This relation does not imply that a particular modal structure corresponds to a particular average speed, but that some modal structures are not compatible with the average speed. In particular, the higher the share of long-distance trips (because of the greater amount of time available for outdoor self-fulfilment), the higher the speed (because of affluence and value of time), the lower the contribution of private cars and other road modes to these trips (because their speed is limited). In the assessment of which modal allocation is compatible with the speed constraint, another element has to be accounted for: household ownership of private vehicles, and the annual use of these vehicles (km/year).

In most regions of the developing world, where slow modes still account for the majority of journeys, overall passenger mobility is in the range 2000-6000 km per person per year in 2000. The situation is totally different in industrialised countries, where road transport is already well developed: personal mobility is nearly 13000 km/capita per year in OECD Asia, 11200 in Europe and more than 23000 in North America.

In the Mid-Pop scenario, VLEEM simulates a convergence of mobility around the world in a range 12000-20000 km/cap per year, due to average speed increase. North America remains distinct from other regions with greater mobility: 29000 km/cap per year. Household ownership of private vehicles is assumed to reach saturation soon in today’s industrialised countries, and before the turn of the century in most developing countries of today, due to a growth in affluence.

The share of private vehicles in personal mobility is calculated to decrease in industrialised countries, down to 41% in the USA and 69% in Europe (from 75% in 2000). In the developing world of today, it is calculated to increase first (up to 85% in Latin America in 2100 from 69% in 2000, for example) and, for some more advanced regions, to start decreasing before the turn of the century.

Figure 1.23: Passenger mobility and economic development (2000-2100)

[29] See in particular the first report of the research study carried out by Enerdata and the Laboratoire d’Économie des Transports for the French Ministry of Transport (PREDIT 3 research programme, 2004).
Freight mobility

As with personal transport, the average speed of freight has increased historically with economic production. This is due to the fact that the value per ton of transported goods increases with economic production: time spent in transit (immobilised) is more and more expensive compared to the cost of the transport, and moves the point of equilibrium towards faster transport solutions.

Here, too, every transport mode has a critical speed for each type of trip (urban versus regional versus long distance), which also depends on the quality of the infrastructure. There is a global relation between the average speed of freight, the structure of mobility according to type of trip and goods, and the relative share of different modes on each trip/type of goods. This relation does not imply that only one modal structure corresponds to one particular average speed, but that some modal structures are not compatible with the average speed. In particular, the higher the share of long distance trips (because of the globalisation of trade), the higher the speed (because of economic production), the lower the contribution of road modes to these trips (because their speed is limited).

In most regions of the developing world, where transport infrastructure is still poor and economic production low, the overall freight mobility is in a range 1000-3000 ton-km/cap per year in 2000. In the industrialised countries of today, where road transport infrastructure is good and economic production high, the range is between 5000 and 15000 ton-km/cap per year. The range in industrialised countries give an indication of the differences in freight transport due to local natural resources and the geographic area.

In the Mid-Pop scenario, there is a clear distinction between three groups of regions:
- a first group, corresponding to regions with one very large country (USA, CIS, China), where the geographical dimension pushes freight mobility to a high level as economic production develops (12000 to 19000 ton-km/cap per year in 2100);
- a second group, corresponding to regions either with one dominant country or highly economically integrated, for which the model calculates a convergence around 8000 ton-km/cap per year (South Asia, Europe, Latin America);
- a third group of all other countries, where freight mobility is calculated to remain close or below 5000 ton-km/cap per year.

The share of road use for freight ranges from 10% to 91% among world regions in 2000: this reflects huge differences in the historical development of the infrastructure, from countries like the USA, CIS or China, where rail infrastructure has been widely developed to cope with the transport of natural resources over long distances, and countries with almost no rail infrastructure, where everything has to be moved by road. In 2100, a much reduced gap is expected between the different world regions (33% to 96%).
to increase by 220%. This is related to the global process of “dematerialisation” of production considered in the scenario, which means that an increasing share of world economic production will be made with high-value, non-material – intangible – production, which has a relatively low need for energy services. As already observed in the 20th century in industrialised countries, the average energy input in economic production is calculated to decrease drastically everywhere from now to 2100.[31].

In today’s more industrialised countries – the USA, Europe, OECD-Asia – the absolute size of the need for energy services is calculated to decrease slightly. In all other regions, it will increase, in particular in China.

1.3.6 | Other economic production

Part of economic production has already been assessed through the basic material requirement for socio-cultural functions: food, shelter and transport infrastructure.

The rest (and bulk) of economic production corresponds to all primary, secondary and tertiary production activities. For reasons explained in the VLEEM1 final report[30], the rest of economic production is assessed as a single entity.

The need for energy services for overall economic production is entirely determined, in VLEEM, by the scale of economic production in society and by its information level.

The same global relation explains both the differences in the needs of different regions for energy services in 2000, and the development of these needs up to the end of the century.

A moderate increase in the need for energy services for economic production up to 2100

In the Mid-Pop scenario, world economic production is calculated to be grow by a factor of 8 between 2000 and 2100, but the need for energy services for economic production is only expected
The higher the level of information, the higher the average value per physical unit of material processed, the higher the share of high stationary exergy needs.

The need for energy services for the production of food, shelter and transport infrastructure is mostly medium exergy, because it is strongly influenced by the processing of primary materials: steel, cement, bricks, glass, fertilisers, etc. For the rest of production, the share of high exergy needs is calculated to increase even faster than on average for the whole production system. Almost 75% of the increase in the need for energy services between 2000 and 2100 corresponds to high stationary exergy.

Because of globalisation and its consequences for the location of basic industries worldwide, the change in the structure of needs according to exergy levels is expected to be very different according to regions. In industrialised countries of today, the medium exergy needs are calculated to decrease drastically in absolute terms; roughly by a factor of 2, while high exergy needs will increase significantly. In developing countries of today, both types of needs are expected to increase, but at a higher speed for high exergy needs.

Figure 1.28: Need for energy services per exergy levels (2000-2100)

1.3.7 | Visions of the world in 2100: uncertainties and consequences for energy-related needs

Uncertainty should be our watchword when looking forward to 2100. But uncertainty carries a particular meaning in backcasting studies. It does not refer to the probability of reaching the target vision, but to the intrinsic consistency of the vision.

In VLEEM, the vision of the world in 2100 described results from certain fundamental assumptions as to the essence of socio-economic development that need to be discussed in order to understand how, and by how much, these assumptions impact the vision.

First, though, the main results of the Mid-Pop scenario will be synthesised.

A overview of the world in the Mid-Pop scenario in 2100

**Western lifestyle and development pattern is a strong influence**

In the Mid-Pop scenario, by 2100, most of the population of today’s developing world is expected to enjoy a similar lifestyle and consumption pattern to that of OECD countries in the last 20 years, with similar individual affluence. They will live in “hard” dwellings, of around 30 m² per inhabitant, and with all the commodities for climatic and sanitary comfort, domestic appliances to replace time and discomfort in daily household tasks, and equipment for indoor leisure. Most will own private vehicles that they will use first for daily transport, then for more distant travelling; they will go on holidays and, increasingly, will fly long-distance for tourism purposes.

As a consequence, their need for energy services in 2100 will be strongly influenced by what we see today in OECD countries. This does not mean that their energy demand per capita will be the same.
Differences in climatic conditions, geography, available primary resources, etc. will certainly result in strong differences in their final energy requirement, not to mention the tremendous possibilities of improving efficiency in supplying energy service needs over the decades.

In the industrialised countries of today, for which no reference exists as to the possible lifestyles and consumption pattern in 2100, a growth in wealth and individual affluence is assumed to be used for three main purposes:
- to pay for the higher price of goods and services coming from the rest of the world, resulting from the increase of exchange rates of national currencies (against the Euro, US$ or Yen) in these countries;
- to increase the living standards of the fraction of the population with low income today in these countries (similar phenomenon as in developing countries);
- to pay for new goods and services, particularly in the field of ICT, leisure and tourism, and to pay for the higher value of goods and services already available.

**More need for energy services per capita, but much less per unit of affluence**

The overall world need for energy services is expected to be multiplied by 3.2 from 2000 to 2100 in the Mid-Pop scenario, while the world population increases by 36%, the number of households more than doubles and global wealth is multiplied by 8.

The needs per capita, which range roughly from 10 to 110 in the world in 2000, are calculated to be multiplied by 2.4 as a world average from 2000 to 2100, with a drastic reduction in the gap among world regions in 2100, between 35 and 140.

This brings about a major shift in the world distribution of need for energy services, from the industrial world of today towards the developing world.

The need for energy services per unit of wealth is calculated to fall by –0.9% per year on average for the world. This is close to the average decrease in energy intensity of GDP in industrialised countries during the 20th century[32].

*Figure 1.29: Overall need for energy services per capita (2000–2100)*

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[32] The calculation on the 20th century is based on Enerdata’s long time series for energy, and estimates of GDP since the 19th century by [A. Maddison].
Centralised transport/distribution systems or through distributed generation.

**More diffuse needs**

One important characteristic of the evolution in energy service needs worldwide is the increasing share of low unit power needs: from 39% to 47% of total needs between 2000 and 2100, at the expense of high unit power needs (whose share declines from 54% to 43%). This evolution implies a greater space for diffuse energy solutions and decentralised energy systems, and reduces the requirement for centralised solutions.

Another important feature is the major reduction in the share of low density/low unit power needs. As these needs are also the most costly to supply from centralised energy systems, this trend may result both in better economic performances by centralised systems, and greater opportunities for decentralised solutions.

**High exergy accounts for the bulk of the increase of the need for energy services**

The share of high exergy needs is calculated to increase drastically worldwide in the Mid-Pop scenario: from 14% to 24% for mobile high exergy (mostly mobility), and from 26% to 41% for stationary high exergy [mostly mechanical power and electrical devices]. Conversely, the share of low exergy needs [low temperature heat] is expected to decline from 14% to 9%, and that of medium exergy [mostly industrial heat], from 46% to 26%.

This structural change in the quality of the need for energy services will have obvious impacts on the required quality of energy providers in 2100 as compared to today. In particular, electricity is likely to play a much greater role, either through centralised transport/distribution systems or through distributed generation.

**Figure 1.30: Distribution of overall needs of energy services per world region (2000-2100)**

![Distribution of overall needs of energy services per world region (2000-2100)](image)

**Figure 1.31: Distribution of overall need for energy services per density (D)/unit power (P) categories**

![Distribution of overall need for energy services per density (D)/unit power (P) categories](image)
A first source of uncertainty: the speed of demographic transition

Women’s emancipation, a fundamental assumption
The fundamental assumption in VLEEM, as well as in the Mid-pop scenario, is that women’s emancipation is a necessary feature of any sustainable long-term vision. This assumption led to a final formalisation in VLEEM in which there is no gender specification, although this has been only partially developed and tested. In particular, there is no formal barrier in the model to women’s access to any level of education or any paid job.

In the Mid-Pop scenario, this assumption has led to further related assumptions:
- expected fertility profiles over time are similar to those of countries where women’s emancipation is now a reality;
- enrolment in secondary and tertiary education is only limited by economic constraints, not by gender;
- participation in the labour market by the age class below retirement is only determined by education, not by gender;
- there is no gender consideration in the evolution of time-budgets.

The uncertainty on this question is not a matter of the universality of the phenomenon during this century, but about its speed and ultimate consequences.

On the one hand, we know that female emancipation, in the sense above, is in conflict today with cultural and religious values and socio-political systems in a number of countries. Assuming there will be female emancipation in these countries means assuming that cultural and religious values, as well as socio-political structures, will change. As indicated in the High-Pop scenario, these changes could be much slower than expected in the Mid-Pop scenario, and lead to a rather different vision in 2100.

On the other hand, it is not clear today to what extent women’s emancipation will impact on fertility rates. To what extent will women prioritise their career over family life and motherhood? Very contrasting situations exist today among advanced industrialised countries, where fertility rates range from 1 to 2.5. Although in the Mid-Pop scenario we project that there will be some stability in the world population after 2050 (in line with the UN medium forecast, which assesses that fertility rates will increase everywhere after the historic decline), alternative scenarios cannot be excluded, where fertility does not resume after the historical low point. This would mean a rather different vision for 2100, and is described in the Low-Pop scenario.

Impacts of different fertility profiles
Uncertainty about the world population, depending as it does on the possible speed and magnitude of the so-called demographic transition, gives us a broad figure of between 7 and 12 billion people in 2100, and between 3.3 and 4.9 billion households.

Figure 1.32: World population and households in the three scenarios (2000-2100)

Because of a lower participation of women in education and paid work, and despite a more favourable overall demographic structure as regard the
ratio of active/non active people, the rise in individual affluence is calculated to be slightly less in the High-Pop scenario compared to the Mid-Pop. One consequence of this would be a slightly lower need for energy services per capita in 2100. Ultimately, however, a delayed demographic transition could translate into need almost 40% higher than in the Mid-Pop scenario in 2100.

**Figure 1.33: World needs for energy services in the three scenarios (2000-2100)**

A second source of uncertainty: the time-budget for paid jobs versus self-fulfilment

VLEEM assumes that time spent in self-fulfilment activities takes the place of time spent doing paid work. Its fundamental assumption is that the trade-off between time allocated to leisure and retirement versus paid work does not jeopardise the global financial balance between savings and financial capital requirements for investment in the production system. This means, firstly, that savings are supposed to match financial capital requirement at every moment worldwide, and secondly, that whatever the savings requirement, consumption adapts to balance the utility of the marginal hour spent consuming and the net revenue of the marginal hour spent working.

The more the people work, the more money they earn, the greater the economic growth and financial capital requirement, the higher the savings needed, but the less time they have for consumption – and therefore the higher the value of time available for consumption compared to the value of time at work, and finally the higher the pressure to reduce working time. Different equilibria are possible, depending on the marginal value of time spent in leisure and in retirement as compared to the marginal salary. In the Mid-Pop scenario, it has been assumed that for all world regions, the overall trend for the coming century will be in line with what has been observed in industrialised countries during the 20th century: the marginal value of time spent pursuing self-fulfilment activities increases faster than the marginal revenue from time spent at work. This brings about a continuous substitution of time spent at work with time spent in self-fulfilment. As shown above, the result is an average working time of around 1,500 hours/year, and retirement at 65.

The uncertainty around this question is twofold:  
- in order to maintain minimum economic growth, governments and business shareholders may force people to work more than they would like to, i.e. beyond the point at which the marginal utilities equalise;  
- an imbalance in treatment of the population in favour of old people may result in large financial transfers from active to inactive people that could jeopardise the equilibrium between global savings/investment and consumption/production, unless active people work more.

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A third major source of uncertainty: social and geo-political “viscosities”

Globalisation and the global village are core assumptions in VLEEM

The structure of VLEEM, as well as the Mid-pop scenario, also assume the free movement of goods, services, people and capital, without restrictions and between all countries, and that all countries will follow a similar welfare development pattern. This is embodied in the model’s structure, since the same set of behavioural relations are used for all world regions. This is also part of the Mid-Pop scenario, which assumes convergence in lifestyles, consumption patterns and technology specifications worldwide.

In the Mid-Pop scenario, we have assumed that the development pattern experienced in today’s industrialised world can be replicated in the developing world, in particular as regard:

- the global relations between demography, education, information, time-use structure and wealth;
- the relation between time-use, information and affluence on the one hand, and need for energy services on the other.

The European model has been taken as a reference for similar regions in terms of population density, size and diversity of member countries. The US model has been taken as a reference for the CIS and China (regions with low population density, a large size and one country dominating).

Uncertainties around basic assumptions

Given that industrialised countries today built their development thanks largely to the exploitation of natural resources in the developing world, the developing world of today has little opportunity to experiment in the future [34]. This could jeopardise the accumulation of physical capital in many countries because they will have to pay a much higher price for natural resources (relative to the local price system) compared to what industrialised countries faced.

In addition, the lifestyle and consumption patterns of industrialised countries have very different cultural and religious roots to those that exist in the developing world. These differences could well result in conflict in the developing world, between traditionalist and more “Westernised” communities, and it is not certain that the outcome conflicts would be to the benefit of the latter (as is assumed in the Mid-Pop storyline). This may have consequences well beyond the impact for female emancipation described above.

Thirdly, there is a link between the lifestyles and consumption patterns in industrialised countries and the fact that labour costs are much lower in many parts of the developing world. This situation, will likely never exist for a large part of the developing world of today, with the effect that the cost of “Western” lifestyles relative to the hourly wage will always be higher for developing countries than it is for industrialised countries today.

Finally, it is questionable whether there are sufficient natural resources available to meet the appetite of 8 billion people for the equipment and consumer goods that go with a Western lifestyle.

Impacts of social and geo-political sticking points

These social and geo-political sticking points could have two major impacts for the results of the Mid-Pop scenario, beyond what has been investigated in relation to women’s emancipation.

The first impact could be a polarisation of the world population into two main groups: those who adopt Western values, who are fully integrated in the world economy, and those who reject these values or are unable to afford the corresponding lifestyles and consumption patterns. This two-speed development would hinder growth in the level of education and the number of people at work, slower growth in labour productivity, slower growth in overall wealth and increasing inequalities in wealth distribution.

The second impact could be increasing barriers to international trade and financial flows, due to growing social unrest in developing countries and political suspicion between rich and poor countries. This would threaten or delay capital
stock building in developing countries, make the growing deficit between savings and the need for financial capital harder to finance in ageing industrialised countries, and exacerbate competition between world regions for natural resources. All this would negatively impact economic growth, and push richer countries to make yet greater efforts to attract better educated people from the developing world, to counter-balance the negative effects on economic growth. This would have further negative knock-on impacts on the developing world, amplifying discrepancies in affluence between rich and poor countries and between rich and poor people within countries.

1.4 | Chapter 4

Three technology paradigms for long-term sustainability

The “energy technology paradigm” describes the technology required to fulfil the need for energy services, along with the availability of resources and technologies in the energy system. Given the amount and structure of energy service needs, the energy technology paradigm will determine the amount and structure of physical energy resources required. Our knowledge today is based mostly on technologies used in the oil and coal paradigm that has dominated the 20th century. Our ability to describe technologies and technology clusters in new paradigms is limited and more speculative, and attempts to quantify their consequences are still very preliminary.

The following quantification, limited to Europe, should thus not be seen as a definitive result, ready to feed into political decision-making, but rather as an illustration of the challenges. This quantification relates mostly to findings about the need for energy services in the mid-pop scenario.

1.4.1 | From energy services to energy demand

A myriad of technologies are used to satisfy society’s various needs. In some instances, numerous technological options co-exist over a long period of time, leading to technological diversity, while in other cases, a single technology dominates for a period before being replaced by another. An example of the first category is the production of domestic hot water using oil, gas and electric boilers. Examples for the second are the steam engine as a source of power for trains and industrial production in the Western hemisphere during most of the 19th century, and the use of internal combustion engines in cars during the 20th century and today.

Because of their importance for energy demand today in Europe, some areas deserve particular attention to understand how energy service needs are converted into final energy demand. These are:
the production of bulk materials, mobility and transportation, and the energy needs of buildings. A shift away from the fossil fuel-based energy system will imply social and technology innovations in these fields that will be detailed in Part 2 of the report.

Production of bulk materials

While the quantity of material use is determined by population, wealth and consumption patterns, its energy efficiency – i.e. specific energy consumption (SEC) per ton produced – is a consequence of the technology used. Most relevant studies on energy efficiency potentials cover technology options up to 2050. Beyond this date, it is almost impossible to estimate specific energy consumption on technological grounds. The specific energy use for the period up to 2100 has to be projected by extrapolation, taking into account the limitations of thermodynamics. Using this approach it is projected that today’s gap to the thermodynamic minimum will be bridged by 2100 by around a half (e.g. for secondary aluminium, primary aluminium and secondary steel) to three-quarters (e.g. for bricks/tiles and cement). The likely progress in this area depends on technology and foreseeable innovations, and differs considerably as shown in the figure below (35).

Figure 1.34: Energy use (in primary energy terms) for the manufacture of bulk materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Year 2000</th>
<th>Year 2100</th>
<th>Thermodynamic minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary steel</td>
<td>195</td>
<td>75</td>
<td>90</td>
</tr>
<tr>
<td>Primary aluminium</td>
<td>195</td>
<td>75</td>
<td>90</td>
</tr>
<tr>
<td>Cement</td>
<td>195</td>
<td>75</td>
<td>90</td>
</tr>
<tr>
<td>Glass</td>
<td>195</td>
<td>75</td>
<td>90</td>
</tr>
<tr>
<td>Paper (1)</td>
<td>195</td>
<td>75</td>
<td>90</td>
</tr>
<tr>
<td>Paper (2)</td>
<td>195</td>
<td>75</td>
<td>90</td>
</tr>
<tr>
<td>Ammonia</td>
<td>195</td>
<td>75</td>
<td>90</td>
</tr>
</tbody>
</table>

(1) No value available for the thermodynamic minimum
(2) Value for thermodynamic minimum is zero (refers to papermaking only)

Mobility and transport

Passenger and freight transport are projected to more than quintuple worldwide from 2000 to 2100. Most of the growth will occur in developing countries, with a projected increase in transport services of a factor of 13, while in industrialised countries it is expected to double.

*Figure 1-35* shows the energy use of all major current transport modes for passengers and freight. Each mode is considered relevant for the long-term future even though it is not known today exactly what form they will take (e.g., new synergies between rail and cars). Totally new or revived transportation technologies such as Zeppelin systems for cargo are not specified but are considered to be rather close in energy efficiency to one of the other modes modelled (e.g. long-distance rail).

The fuel options foreseen for the long term are liquid hydrocarbons (e.g., in the form of gasoline, diesel and kerosene), hydrogen and electricity. Liquid hydrocarbons may be derived from fossil fuels (oil, gas, coal) or biomass (e.g., vegetable oil, starch crops or wood). The various fuels are used in internal combustion engines (ICE), hybrid systems, fuel cells or gas turbines (especially for planes). Electricity is also considered as a long-term option for various modes (road vehicles and rail). Further fuel options such as methanol or compressed air are not explicitly included but lie within the range of fuel efficiency for the options considered. Propagation systems that are not currently considered feasible for large-scale use in transport – such as systems based on nuclear energy or photovoltaics – are not included. Any breakthroughs in these areas could thus undermine the study’s conclusions.

(35) Energy use in *Figure 1-34* is expressed in terms of primary energy in order to account for the conversion efficiencies for generating power and heat. Efficiencies of 33% for power and of 90% for steam have been assumed for this purpose. While this allows first comparisons across technologies on the energy demand side the integration with the energy supply side requires scenario-specific adaptations.
The values shown in this figure are expressed as final energy use since the energy efficiency and emissions for power and hydrogen production will depend decisively on technology choices on the supply side and should hence be analysed from a systems perspective. Nevertheless it is interesting to compare end-use energy efficiencies. Details about future technologies that might be available in Europe in 2050 are given in Part 2 of the report.

While transport technology can be assumed to be globally available due to the trade in vehicles and rapid transfer of production systems, specific energy use will differ by region, for these reasons: certain wealthy regions may change their car stock more rapidly, thereby moving quickly towards high overall fuel efficiency of the total fleet, while in other high-income regions affluence may continue to lead to overpowered vehicles with relatively high energy use. The opposite could be true for developing countries: there may be low efficiencies due to an aged stock while elsewhere lower affluence may lead to higher shares of fuel-efficient vehicles. Differences in occupancy rates across the globe are likely to remain to some extent (the values in Figure 1-35 refer to energy use per person-km and ton-km and are hence determined by multiplying vehicle efficiency with occupancy rate).

**Figure 1.35: Specific energy consumption of transport modes in Europe, 2000 and 2100**

Residential and public/commercial buildings

While details of technologies likely to develop in Europe up to 2050 are provided in Part 2, here we offer more general considerations about the potential to decouple energy demand from the need for energy services over the next century.

**Climatic comfort**

For several energy services, in particular climatic comfort and lighting, needs are related to floor space. In Europe, space heating accounts for the largest quantity by far of final energy used in buildings. On the other hand, it has been demonstrated that not only low energy houses but also passive houses and zero energy houses are technically feasible. Passive houses can be built at an acceptable cost while future R&D, in combination with public policy, is expected to lead to a similar situation for zero energy houses on a large scale. Combining the gradual replacement (incl. renovation) of the building stock with information about the specific energy use of new buildings shows that total final energy demand for domestic space heating could decrease in Europe from 8000 PJ in 2000 to around 1200 PJ in 2100, i.e. by 85%. Depending on the climatic conditions and the size and development of population, consumption could also decrease in other world regions of a similar size (e.g. more than 5000 PJ or 80-90% for North America and the former USSR) or – in most cases – lower (e.g. Asia Pacific OECD). In some “cold” developing regions, more final energy might be required for space heating because higher comfort levels (more heated space, higher room temperatures) overcompensate for (very substantial) energy efficiency gains.
Two groups of electrical appliances can be distinguished. The first is composed of appliances that are well established on the market and for which both current specific energy use is well known and future energy use can be projected. In the case of lighting, for example, a relationship can be established with floor space and there are limited and clear technological options (compact fluorescent bulbs and LED bulbs with specific energy savings compared to incandescent bulbs of 70% and 90% respectively). The situation is similarly clear for food conservation (refrigerators and freezers), dishwashers and washing machines. For other appliances, including ICT devices, the situation is so diverse that it constitutes a major source of uncertainty for overall household electricity use in future projections.

### 1.4.2 | Continuing the fossil fuels paradigm

Fossil fuels could continue as the basis of the energy system if climatic and local environment problems could be solved, in particular through large-scale carbon capture and sequestration. In this case, though, there would be limited progress towards decoupling energy demand from energy service needs, because of the continuation of the same paradigm.

#### The challenges

Fossil fuels supply roughly 81% of the world’s primary energy demand today, and total energy demand is expected to rise in the coming decades. Even if the share of fossil fuels is expected to decrease slowly in the short term (Enerdata Enerfuture, 2009), demand for fossil fuels will still increase. Two major challenges are expected for the future.

1. Fossil fuel resources which are not available today or only at an unacceptably high cost will need to be made available at competitive prices. This will require a massive investment in exploration and mining infrastructure.
2. CO₂ emissions will need to be captured and stored safely for centuries.

### Other energy services in buildings

The technical possibilities for decoupling energy demand from the needs of energy services differ substantially according to energy service. For space cooling, it is mostly a matter of adequate architectural measures. For sanitary hot water, further efficiencies are relatively limited at the user’s end in industrialised countries, due to high conversion efficiencies and unavoidable losses due to distribution and storage. But large savings are possible when it comes to heating water for commercial purposes, for example by using renewable energy such as solar thermal panels, geothermal energy or seasonal heat storage in combination with heat pumps. In developing countries, the potential to improve energy efficiency is very underexploited, in particular in case of heating water using coal and biomass.

Like with sanitary hot water, while the potential to make cooking more energy efficient is rather limited in industrialised countries, there are major inefficiencies in developing countries in particular. Besides technical efficiencies, the variation in energy consumption can also be explained by cultural differences in food preparation throughout the world, as well as the increasing consumption of convenience food (especially in combination with microwave preparation).

#### Table 1.1: Specific energy use and share of new buildings entering the stock in Europe for the years 2000 and 2100

<table>
<thead>
<tr>
<th></th>
<th>Specific energy use MJ/m²/a</th>
<th>Share of new buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2000</td>
</tr>
<tr>
<td>Zero energy house</td>
<td>0</td>
<td>2%</td>
</tr>
<tr>
<td>Passive energy house,</td>
<td>54</td>
<td>5%</td>
</tr>
<tr>
<td>higher bound</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low energy house,</td>
<td>108</td>
<td>30%</td>
</tr>
<tr>
<td>lower bound</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low energy house,</td>
<td>252</td>
<td>63%</td>
</tr>
<tr>
<td>higher bound</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Two groups of electrical appliances can be distinguished.

- **Lighting**: Relationship established with floor space. Limited and clear technological options (compact fluorescent bulbs and LED bulbs with specific energy savings compared to incandescent bulbs of 70% and 90% respectively).
- **Food conservation**: Clear options for refrigerators and freezers, dishwashers, and washing machines.

For other appliances, including ICT devices, the situation is so diverse that it constitutes a major source of uncertainty for overall household electricity use in future projections.
Only if both challenges could be solved without major cost penalty would fossil fuels remain our principal energy sources, even in a future in which sustainability criteria are applied.

The availability of fossil fuels has been studied by various sources. The number of reserves are mainly consistent, but figures concerning resources differ widely. In the following investigation the values published by BGR (BGR, 2002) will be used as reference. The results for the major fossil energy carriers are quoted in Table 1.2.

The most important fossil fuel for the future is coal, which represents more than 50 percent of the combined reserves and resources. The high values for unconventional gas resources discussed in the last ten years have recently been questioned. Values quoted here are thus in a conservative range.

The second major challenge concerns greenhouse gas (GHG) emissions. To be sustainable, a continued dependence on fossil fuels would need to be compatible with a drastic reduction in GHG emissions. In VLEEM, for sustainability criteria, it was assumed that emissions are cut by 10% every decade. Up to 2100 Europe would have to reduce its GHG emissions to 35% of the current level, a modest requirement compared to some political demands to reduce GHG emissions in OECD countries by 80% by 2050 (this will be further discussed in part 2 of the report). Even so, cutting emissions to 35% of current levels by 2100 still poses a severe challenge.

Energy-related CO₂ emissions occur in all sectors. Looking at figures for the EU given in figure below, it is obvious that the electricity and transport sectors should be prioritised for emissions cuts, followed by buildings and, finally, industry.

**Figure 1.36: Energy-related CO₂ emissions in the EU in 2009**

![Graph showing energy-related CO₂ emissions in the EU in 2009](Image)

Source: Enerdata.

Selecting which sectors should be targeted for greatest reductions is a question of political, economic and environmental reasoning, as well as wider acceptance. The EU emissions trading scheme demonstrates that equal treatment of all sectors cannot be expected from

**Table 1.2: Table of energy reserves and resources**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional oil</td>
<td>6360</td>
<td>3515</td>
<td>8821</td>
<td>0.07</td>
<td>617</td>
</tr>
<tr>
<td>Unconventional oil</td>
<td>2761</td>
<td>10460</td>
<td>7991</td>
<td>0.07</td>
<td>559</td>
</tr>
<tr>
<td>Conventional gas</td>
<td>5109</td>
<td>6886</td>
<td>9929</td>
<td>0.07</td>
<td>695</td>
</tr>
<tr>
<td>Unconventional gas</td>
<td>63</td>
<td>48633</td>
<td>24390</td>
<td>0.07</td>
<td>1707</td>
</tr>
<tr>
<td>Coal</td>
<td>17668</td>
<td>103898</td>
<td>69617</td>
<td>0.07</td>
<td>4873</td>
</tr>
<tr>
<td>Lignite</td>
<td>1963</td>
<td>12218</td>
<td>10516</td>
<td>0.07</td>
<td>736</td>
</tr>
<tr>
<td>Uran</td>
<td>644</td>
<td>2139</td>
<td>644</td>
<td>0.40</td>
<td>857</td>
</tr>
<tr>
<td>Thorium</td>
<td>908</td>
<td>964</td>
<td>2139</td>
<td>0.07</td>
<td>111</td>
</tr>
<tr>
<td>Sum</td>
<td>35476</td>
<td>188713</td>
<td>2139</td>
<td>0.07</td>
<td>10155</td>
</tr>
</tbody>
</table>

political measures. Under the scheme, only sites with over 20 MW thermal power and, in the near future, air transport, are regulated.

Supplying the need for energy services with fossil fuels

Many fossil fuels still reach consumers as final energy carriers, mainly natural gas, various oil products, including diesel and gasoline, and coal used in industry, mainly. Even were there to be continued high use of fossil fuels, therefore, this is expected to change, for the simple reason that CO₂ emissions can only be captured and stored economically in large central installations. For which sectors, therefore, would it make sense to continue using fossil fuels and which should be switched to hydrogen and electricity?

We assume that Europe will not be allowed to emit more than roughly 2 Gt CO₂ equivalent in 2100. This corresponds to 37 EJ of natural gas, 25 EJ of oil and a little less than 22 EJ of coal which could still be combusted without capturing and storing their CO₂ emissions. A key question in this respect is whether hydrogen will be making a major contribution by then in the final energy sector, or will energy savings and electricity together with the fossil fuels outlined be sufficient to supply all energy service needs. Given that roughly 27 EJ/a of natural gas would be available to Europe each year, it makes sense to use this source of uncaptured combustion first.

Transport sector

When major car suppliers announced they were introducing fuel cells in the first decade of the 21st century, this was widely seen as the first step towards a hydrogen economy. Fuel cells promise not only good efficiency, but also, if fuelled by hydrogen, they produce no toxic local emissions. This latter argument makes them especially suitable for densely populated areas. But car industry announcements on the subject have rather quietened down of late, with more focus now given to electric and hybrid cars (with both an internal combustion engine and an electric motor), which opens a further possibility for increasing car efficiency. The fuel cell is now, again, viewed more as technology for the long-term.

To start with, a couple of transport options should be investigated and compared. The transport sector could firstly shift most of its problems to the electricity sector if a major shift in transport modes could be initiated. Major trends do not hint at this trend, but the introduction of high-speed trains does offer an attractive alternative for inter-city transport.

The study compares different fuel and traction concepts for road vehicles. For the first investigation it assumes no sequestration of CO₂. Neither does it compare cars that produce hydrogen on board, using ordinary fuels and fuel cells which can directly utilise hydrocarbons. One striking result is that hybrid cars running on natural gas perform quite well compared to hydrogen-driven fuel cell cars. The latter option certainly offers the possibility to sequester CO₂ during the production of hydrogen. Options like the enhanced use of biofuels will be discussed later.

Recent studies have questioned the rationale of introducing hydrogen into the transport sector due to the inefficiency of the supply chain (Bossel, 2003)[37]: a hydrogen infrastructure is associated with high losses in the transport and storage sector. The VLEEM comparison was based on an assumed transport and storage efficiency of 80%, and shows the fuel cell option still as the most efficient. Other criticisms relate to the high assumed efficiency of the fuel cell. Although the figures do not reflect the results of recent developments, they reflect the principle determined by physics. The development of conventional power plants is a good example of how physical limits, given here by the Carnot cycle, are approached incrementally over a hundred years.

The housing and service sector

Development in the housing sector can be characterised by two trends: greater electricity demand in response to the growing need for high exergy energy services; a strong reduction in

heat demand, especially for new homes, due to improved efficiency in supplying low exergy energy service needs. It is assumed that all houses built after 2010 have quite strict heat standards (<25 kWh/m²) for space heat demand. Assuming that new building standards also avoid any major demand for cooling in summer, no major cooling demand is assumed. By the end of the century, it is assumed that the main final energy carrier to households will be electricity. This assumption does, however, depend on quite prompt action by national and European authorities to ensure that new housing standards, which are technically achievable at acceptable costs, are applied everywhere in Europe [38].

A few end-use technologies using various fuels can be applied to deliver heat. New gas and oil condensation boilers, electric resistance heating, heat pumps driven by gas or electricity, and small combined heat and power plants (CHP) based on various technologies like micro-turbines, Stirling motors and in the future fuel cells, district heating and geothermal heat.

It is assumed that for the existing housing stock a variety of heating technologies is applied. New houses are only supplied by electricity, if possible using heat pumps.

Industry sector
The industrial sector still uses the whole variety of fossil fuels: coal, natural gas and oil products. It also consumes electricity and even hydrogen. The choice of the appropriate final energy carrier depends on availability, cost and environmental issues. Industry could be the first sector to use large amounts of hydrogen, and it also seems feasible that CO₂ emissions are captured and sequestered in major industries.

In the continuation of the fossil fuel paradigm, few new technologies are expected to enter the scene.

Since CO₂ capture will be necessary for the electricity sector, it is assumed that this technology will also be used in industry, particularly the bulk material industries: steel, cement, etc.

The infrastructure required to transport captured CO₂ from power plants to storage sites will also be used by industry, but at a much later stage.

Technologies
Fossil fuels dominate the energy system. Most energy technologies, power plants, boilers and traction systems need fossil fuels. Technologies such as the internal combustion engine (ICE) are over 100 years old and are highly developed already (although still undergoing improvement), in common with many technologies that use fossil fuels. Consider developments in the efficiency of power plants: steam turbines were developed at the end of the 19th century, and gas turbines as plane engines during World War Two. The increase in plant efficiency is outlined in the figure below.

Figure 1.37: Development of the efficiency of the steam cycle

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[36] This is the purpose of the European Revised Energy Performance Directive for Buildings EPBD: The EU addressed this large energy use with the Directive for the Energy Performance of Buildings (EPBD), adopted in December 2002. The directive provided a common methodology for calculating the energy performance of buildings and obliged member states to draw up minimum standards. These should be applied to all new buildings and to existing buildings with a usable floor area above 1000 m² when they undergo a major renovation.
The pressing new challenge for fossil fuel technologies is how to separate out the CO$_2$, as this is essential if sustainability criteria are to be fulfilled. CO$_2$ separation is a proven process technology, and separated out CO$_2$ can be used in many industrial processes (for example enhanced oil recovery). The question is therefore not if CO$_2$ can be separated, but how the additional steps in the process will influence the technical and especially the economic performance of the various energy conversion technologies.

A whole field of concept studies is under way to include CO$_2$ separation into power plants, both coal and gas-fired. We will focus on coal power plants alone. Three major technology lines are discussed: Internal Gasification Combined Cycle coal power plants with CO$_2$ separation in the gasification step. Here, the carbon is separated from the fuel before combustion. The fuel remaining is hydrogen. The second option is to continue with combustion but using an oxygen atmosphere, which gives a flue gas stream of highly enriched CO$_2$. The third and last option is to separate the CO$_2$ from the flue gas, using various ab- and adsorption methods, cold traps or membranes.

The remaining issue is the identification and qualification of suitable CO$_2$ storage places.

These need to be capable of storing 4 Gt of CO$_2$ every year by the turn of the next century, and retaining the CO$_2$ for many future centuries. Accidents in which large amounts of CO$_2$ are suddenly released are not acceptable. Again a family of options is discussed [39]. Most of the discussions focus on options for geological storage or in the ocean. It is possible, it must be added, to convert CO$_2$ to carbonates or other solids. Such a process would no doubt challenge the technological and economical performance of the technology, but it would also represent the safest option and relax limits on storage size.

If the fossil fuels paradigm were to continue, hydrogen would be expected to enter the scene only as an energy carrier and chemical agent in process steps in power plants or large industrial installations. Using hydrogen as a major final energy carrier for transport, industry and households, although possible, would depend on a completely new infrastructure, which is not part of the paradigm’s philosophy.

Balancing demand and supply in the fossil paradigm: the case of Europe

Coal would play a major contribution in any continuation of the fossil fuel paradigm, becoming by far the largest primary energy source by 2100, a result consistent with the resource availability. Only in a few niche markets would oil still be used. Little of the coal would be produced in Europe, and efficient and cheap coal transport would be possible by sea and major rivers and canals. The need to store CO$_2$ would make siting issues more complex. At the start of industrialisation, industries moved, or were created near to coal fields. In future, industry, especially power plants, will move to places mainly by the sea, offering cheap and easy access to the world coal market and close to CO$_2$ storage capacities.

Figure 1.38: Highlights of primary energy supply in Europe in the fossil paradigm by 2100

The amount of carbon needing to be stored is enormous, and handling CO$_2$ “waste” becomes a significant sector in the economy. There will be continuous scrutiny of regulations, safety and environmental standards at CO$_2$ storage facilities, any CO$_2$ accidents might challenge public acceptance. On the other hand, the whole

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The figure below describes the development of CO₂ emissions and the fractions which are released to the atmosphere or stored. In 2100 more than 4 Gt CO₂ need to be stored each year. 

**Figure 1.39: CO₂ emissions and storage in Europe in the fossil paradigm**

![Graph showing CO₂ emissions and storage in Europe](image)

**Major milestones**

The major milestones and developments of the case are described in figure below. The most important milestones are the feasibility test for zero emission coal power plants and EU regulations for the building sector. Zero emission coal power plants are not competitive without special regulations. And since all cases assume that CO₂ emissions in Europe will have to decrease by roughly 10% each decade, it is likely that the emissions trading scheme will continue throughout the century. CO₂ prices of 40 euro per tonne could make zero emission coal power plants competitive with conventional coal power plants. In the following the major milestones should be explained a little more in detail.

**Fusion in the continuation of the fossil paradigm**

One of the major R&D items for the EU and several EU member states is the development of nuclear fusion. Nuclear fusion will not be commercially available before 2050-2060, and is considered here for its future potential role in the fossil fuels paradigm. In principle all paradigms considered by VLEEM leave or request space for new technologies, if they are cost competitive and fit with the rest of the system. For the fossil fuels paradigm,
it is assumed that coal power plants with CCS progressively gain 70% of the electricity market. It would certainly be simpler if fusion power plants were built instead. Here it is assumed that in 2100 20% of the electricity marked will be covered by fusion, thanks to certain conditions that would favour its installation. First, coal plants need ideally to be sited at the coast or at least beside rivers; a considerable CO₂ sink has to be close and enough high voltage lines need to be installed to transport electricity to the demand centres. For possible fusion plant sites there are many fewer constraints, which would simplify the network structure and other issues.

**Figure 1.41: Electricity supply in the fossil paradigm with fusion**

Installing fusion plants would also reduce dependence on coal prices, a feature that would become paramount in the fossil fuels paradigm.

**Major milestones**

The major milestones necessary to develop nuclear fusion are shown in the figure below. The milestones can be grouped into three categories: construction and operation of ITER, development of materials, and construction and operation of DEMO.

**1.4.3 | Nuclear power and hydrogen as a new possible paradigm**

Nuclear power and hydrogen could become the core of a new paradigm, in particular if CCS remains limited for technical or economic reasons, or because of a lack of public acceptance. But enormous progress is required first in the fields of nuclear security and waste management. Electricity may bring higher end-use efficiency, but there is no reason why a nuclear and hydrogen paradigm would have any impact on end-use technologies. Only limited progress could be expected in decoupling electricity demand from the need for energy services.

**The challenges**

Nuclear power currently supplies 28% of Europe’s total electricity demand; in certain member states rising to 76%. The challenges it poses to a sustainable energy future are as follows: can the resource base supply the demand or will breeder technologies become necessary?
Can it be produced with a guarantee of no catastrophe? Will it be possible to reduce the high-level waste to small, acceptable amounts?

In the past, several strategies were developed with a view to supplying electricity from nuclear power for centuries to come. A mix of breeder, high-temperature and converter reactors, their goal was to develop a kind of closed nuclear cycle which would supply electricity in the order of 10 TW with low fuel input (a few thousand tons of uranium and plutonium) and fuel output below a few thousand tons of fission products. The development of breeder reactors and reprocessing plants dominated energy research in the Seventies. Major projects were planned, built and some even began operation. But the success of many of these projects, such as Super Phenix and Monju, was questionable. Not due to problems of principle – the first nuclear reactor constructed by Fermi was already a breeder reactor – but to technical problems caused mainly by the cooling medium, sodium. (Concepts using other cooling media are in principle possible.)

Energy studies in the late Seventies and early Eighties looked into the feasibility of using more nuclear power. One option that seemed to offer the potential to reach a nearly closed loop was the use of Liquid Metal Fast Breeder Reactors (LMFBR) in combination with Thorium High Temperature Reactors (THTR).

There is no single strategy for a renewed development of an integrated fission system, which could supply electricity for centuries to come with low fuel demand and low waste production. The most prominent research initiative is the Generation IV initiative. Some of the reactor types designed within this initiative are breeder reactors. The question of resource availability is strongly relaxed in the case presented; without this, a high fission case could not be designed. This implies that in parallel with conventional converter reactors, new reactor types need to be developed, with much better fuel utilisation. An alternative could be that much more uranium is available at a higher price. Uranium costs account today for 0.1-0.2 eurocent/kWh. Even if the cost were to rise tenfold, the price of electricity would stay competitive. Since fission is only considered to be competitive if the waste can be efficiently disposed of, fast reactors and reprocessing plants need to be developed. These technologies could then also be used to breed new fissile fuel.

Supplying the need for energy services in the nuclear and hydrogen paradigm

Nuclear power plants produce heat which is transformed into electricity and, in future, hydrogen too. Electricity and hydrogen could therefore play a major role as final energy carriers. In the past, it was expected that fission would also be used to provide heat for district heating systems and as a traction system in ships. It is still used in submarines.

Transport sector

This paradigm offers the opportunity to supply hydrogen from nuclear high temperature reactors, since the thermo-chemical splitting of water is in principle possible. The efficiency would be roughly 50% and is slightly higher than producing electricity first and then transforming it via electrolysis to hydrogen. Neither technology is yet available. It is therefore assumed that this option only becomes available in the second half of the century.

Housing

The housing sector is expected to be the same as in the fossil fuels paradigm. The sector is characterised by strong reductions in the demand for space heating and the introduction of electricity as final energy carrier for new homes. It was not assumed that the electricity in new homes would be used in combination with heat pumps. This option would offer an additional reduction in the space heat demand.

Industry

Industry uses the remaining fossil fuels. In principle it would also be possible to introduce hydrogen into the industrial sector. The rationale for introducing hydrogen in the transport sector was driven by the potential for introducing very efficient fuel cells. If the implementation of fuel cells
Technologies

The technological steps in nuclear fission are characterised by generations. Most reactors currently operating are part of Generation II; newly-developed reactors like the EPR, the SWR 1000 and AP1000 are Generation III, and a major initiative is under way to develop Generation IV reactors. After Generation IV would come the development of an integrated reactor fuel system, which makes it possible to increase the fuel basis and considerably reduce high-level waste. Generation IV includes fast neutron reactors, which would be able to widen the fuel base (depleted uranium and thorium could be used).

Technology research in nuclear fission has changed significantly in recent decades.

Hereafter, we place the main emphasis on technologies, which will be capable to convert high-level radioactive waste to low-level waste.

Balancing demand and supply in the nuclear and hydrogen paradigm: the case of Europe

In the nuclear and hydrogen paradigm, nuclear energy supplies over 60% of primary energy and 70% of electricity demand in 2100. Hydrogen for cars, trucks and buses is also produced by nuclear.

Due to the global scarcity of uranium, new fuel and reactor types, such as fast breeders, would need to be installed to make this scenario feasible.

The Figure 1.43 shows the development of the primary energy supply in the nuclear and hydrogen paradigm in Europe. With existing nuclear technologies, uranium resources would not be sufficient to supply this case.

From 2050 onwards nuclear could start to supply not only electricity but also hydrogen, which is then used in the transport sector. Candidates for hydrogen production are High Temperature Reactors (HTR). The massive introduction of nuclear will certainly change the profile of the energy system. One change might be that the global energy trade is massively reduced. Electricity and hydrogen would be supplied in regional centres, close to consumers. The only reason for trade could be, for example, price differences, induced by different environmental standards.

Radioactive waste is the principal issue of the high nuclear case. The production of large amounts of radioactive waste, which would last for thousands of years, appears incompatible with the underlying sustainability concept. So, could this waste be reduced and, if so, how?

Options to seriously reduce nuclear waste include the use of innovative reactor types, like CAPRA and ADS, but also very advanced reprocessing facilities for the different fuel types. Most of these fuels and processes are not yet available and would need to be developed in the coming decades. An assessment has been undertaken on the potential development of the stock of plutonium [PUOut storage] and minor actinides [MAOut storage] if these innovative fuels and processes were to be developed. It indicates that it is, in principle, possible to reduce the plutonium stock such that sustainability criteria would be fulfilled.
Major milestones

The major milestones are shown in the figure below. These milestones can be distinguished as: social and political measures necessary to regain public acceptance of nuclear power; major R&D measures; investments in new nuclear capacity; and investments in reactors and reprocessing plants necessary to destroy high-level radioactive waste.

1.4.4 | Renewable energy flows as the core of a green paradigm

Renewables might also become the core of a new paradigm, in particular if CCS remains limited and there is no rapid breakthrough in nuclear technology. Renewables would bring about a totally different way of supplying the need for energy services, and contribute to the decoupling of energy demand from energy service needs.

The challenges

Natural energy flows are huge; several orders of magnitudes larger than the demand for energy today and that anticipated for the future [40]. Still, serious challenges have to be overcome before renewable energies can supply any major fraction of our energy demand.

The challenges are related to storage and to the power density of the energy flows compared with the power density of needs and the related high costs of collecting the energy. They are also related to the geographical disparity in the flows compared to needs, and in time patterns: the annual, seasonal and daily variations of solar radiation and wind speed, for example. They can be grouped into three major categories:

- supplying low power, low spatial density energy services is mostly a question of time patterns;
- supplying high power, high spatial density energy services presents a challenge firstly in

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terms of the cost of collecting and concentrating natural energy flows, and secondly in terms of geographical disparities;

- supplying energy services from distant natural energy sources, which is primarily a matter of geographical disparities and transport costs and feasibilities.

To highlight these three categories, two visions are explored:

- a conservative vision, where most renewable energy used in Europe is harvested in Europe;
- a radical picture, which assumes that at least all electricity consumed in Europe is supplied by renewable energies, within or outside Europe.

It is important to remind the reader that the size and complexity of a technological system have an influence on governance and participation in decision-making processes. Within VLEEM this problem was discussed, but there was no methodological investigation of the gains and losses with respect to the system’s complexity. The interested reader will find various approaches in the literature.\textsuperscript{[41]}

**Supplying the needs of energy services in the renewables paradigm: a conservative view**

Renewable energy sources cover up to 50\% of primary energy in the year 2100. Biomass dominates, not wind or solar power, although the underlying assumption – that biomass can supply roughly 20 EJ in Europe to primary energy – is optimistic. Progress in agriculture and harvesting technologies make the assumption more believable. Renewable energies penetrate all sectors: biomass in transport and industry; solar PV and wind in the electricity sector; and solar thermal in the heat and electricity sector.

**Transport**

The transport sector is assumed to undergo three major transitions: an increase in car efficiency by introducing hybrid cars; a shift from gasoline to biofuels and electricity; and then a shift to fuel cells fuelled by hydrogen produced from biomass. In the modelling, the route to biofuels is kept open for the time being. It is assumed that biomass can be converted to biofuels with an overall efficiency of 60\% and later to hydrogen with 70\%.

**Housing**

Space heat demand is again expected to decrease, as in the previous cases. The only difference is that it is expected that solar power will meet 25\% of domestic heating demand over the course of the 21st century.

**Industry**

Industry uses some of the remaining fossil fuels, but also biomass. Production of plastic presents a problem, as this is currently based on oil. Biomass cannot replace all oil products used in plastic production.

Electricity is produced with a mix of PV, imported solar thermal electricity (over fairly short distances), wind and, as a back-up, mainly natural gas. This mix means that no seasonal storage systems are necessary, at this stage.

**Technologies**

Most of the technologies required to convert natural energy flows to useful energies have been known for some time. The only exception is photovoltaic technology, which was developed in the early Sixties.

movement of humans across the planet. In many parts of the world, burning biomass is still a key source of energy, notably in the informal non-commercial energy sector. This use of biomass cannot be considered sustainable, however: 1) more biomass is used than grows every year; 2) the use of fire indoors damages human health.

Wind
Estimates including on- and off-shore wind potentials show that wind power might emerge to become one of the dominant future electricity sources. In some European countries – namely Denmark, Germany and Spain – wind energy is playing a growing role.

Hydro power
Hydro power delivers roughly 16% of the global electricity supply (2008). Within Europe most of its potential is already used, although this is far from the case elsewhere.

Other
Other technologies that can be envisioned include special power towers – using up-wind or falling wind – and geothermal energy.

As was shown in the first example in the case of renewable energies, the overall system design is extremely important and needs special attention. Technologies for the transport and storage of electricity are of growing importance and need special consideration at R&D level.

Balancing demand and supply in the renewables paradigm: the case of Europe

By 2100 roughly 50% of primary energy is supplied by renewable energy sources in Europe. Biomass accounts for 25% of this fraction, solar in Europe 11% and wind roughly 7%. Electricity from solar thermal power plants is imported to Europe, mostly from North Africa. Nuclear energy is expected to fade out by the year 2100.

Solar
With the exception of geothermal energies, solar is the primary energy source of all energy flows in nature. Many people expect (Haefele, 1981[42]) that solar will play a dominant role in a world supplied mainly by renewable energies, yet only a fraction of primary energy was supplied by solar technology in 2000. The conversion of solar power to commercial energy carriers can be made in various ways: one route is to use the heat produced by radiation, the other is to use the radiation itself to produce electricity in PV-cells. Only in very focused systems can the sort of temperatures be achieved that are required to produce electricity or split water to produce hydrogen (the latter process would seem to be feasible only with the help of catalysts, as otherwise temperatures would need to reach over 2000°C). All the technologies are developed and used either in niche markets or thanks to special financial support.

Biomass
Early humans began to master fire roughly 4 million years ago, in one of the most important cultural achievements of man. Although there is no clear proof on the subject, control of fire seems to have been a key element in the
Biomass is the most important energy source, and is mostly used to supply heat initially. It is subsequently mainly used for biofuels and later for hydrogen production and direct use in industry, not least as feedstock.

The electricity sector undergoes a major transition. By 2100, wind and solar are the biggest electricity sources. The rest of the system follows this development. Classical base load plants disappear and are replaced by fast load following, but still efficient gas power plants. A more in-depth analysis of this case would need to investigate the possibility that the gas is steadily replaced by hydrogen, produced by PV and wind power plants in off-peak hours.

Major milestones

The most important issues would be sourcing an efficient supply of biomass and technologies to convert biomass to end-energy carriers like biofuels, feedstock for industry and, later, hydrogen. In the electricity sector, wind and solar technologies need to become competitive in the next 50 years. Efficient gas plants need to be developed to balance the intermittent supply of wind and solar power.

A radical view for renewables at the turn of the century: the “Global Link”

Two central issues for renewable energies are wide geographic variability and the intermittent nature of wind and solar power.

A solution to this could be a so-called “Global Link”, in which electricity networks are built to span the entire planet. Based on the ideas of Richard Buckminster Fuller in the Seventies, this would involve setting up a mesh of electricity networks.
The development of a global grid would be a major attraction if we were to shift towards a renewable paradigm, as it would offer the opportunity to harvest renewable energy at locations far from consumption areas. Examples might include:

- large untapped hydroelectric sites in Latin America, Canada, Alaska, Siberia, Southeast Asia and Africa;
- tidal sites in Argentina, Canada, Siberia, China, Australia and India;
- solar potential around the world: in Mexico, the US, Africa, the Middle East, Russia, India, China and Australia;
- geothermal potential around the Pacific Ocean’s “Ring of Fire”, in the Rift Valley of Africa, and Iceland.

transmission lines across the world, connecting advantageous sites for renewable energy sources with demand centres, and with a wide geographic spread of different converters to smooth the stochastic nature of the supply. For VLEEM, a special tool – the TASES programme – was designed to study the case.

Whereas 30 years ago electricity could be transported efficiently only over about 500 km, new technologies enable cost-effective transport over 6000 km and more (Klein, 1994)\(^45\). Losses of 3% over 1000 km appear reasonable for high voltage connections. The transport of electricity could thus become viable on a scale far beyond the local level, and the exchange of electricity between northern and southern hemispheres economically feasible.
Advantages of an electrically connected world include that electrical energy has an exergy/energy "ratio of unity", so is reasonable to transport it in this form, too, and the potential it offers to iron out local fluctuations in supply and demand. The global distribution of wind turbines, for example, shows one of the highest levels of natural variability.

A number of reasons would support efforts to establish a global electricity grid, an aim to which one organisation, the Global Energy Network Institute (GENI), is dedicated (46). In some respects, the world is not far from a global linkage, taking into account all the existing long-haul transmission lines.

(45) Klein, Ch. [1994], Global energy grid a salvation for developing countries.

2 | Part 2

Energy and environment transition in the EU to 2050

Human behaviour has been addressed thus far in a consideration of how time is used in a variety of socio-cultural functions. Part 1 showed the driving role of these functions in the dynamics of the need for energy services. Depending on the technologies and energy carriers available to fulfil their needs, on cost and their own affluence, people have to make choices as regards their own level of satisfaction. This is what terms such as “utility” and “system of preferences” try to capture, and which define “social behaviours”. Technology paradigms, through the availability of technologies and energy carriers and their costs, have an impact on the relative utilities of goods and services, and the preference system. They thus also impact how needs are fulfilled (the relation between energy services and final/primary energy demand) and the relative levels of need fulfilment.

A discussion of the energy and environment transition defines precisely this change in the energy technology paradigm. In order to understand the main consequences of the transition in the energy sector, we need to look at how the changes would affect social behaviour. What follows in this part of the report is an investigation on this subject for the EU. We will limit our investigation to the period from now up until 2050, because the assessment relates so closely to technologies.

2.1 | Chapter 1

Technological innovations and related behaviour

2.1.1 | Innovations in building and housing

In buildings, energy is used to fulfil various services and for different applications. In each case, the level of energy consumption and the related greenhouse gas (GHG) emissions depend on a variety of parameters, most of which may be influenced by technological choice, building operation and consumption pattern.

The relative relevance of different approaches towards low / post-carbon buildings depends on the initial situation and the CO₂ mitigation potential in each case (construction of new buildings, retrofit or replacement of existing buildings) and on climatic conditions. In terms of primary energy consumption and related GHG emissions, space heating is today the most important energy service in most regions of Europe. In Southern Europe (Portugal, Spain, southern France, Italy, Greece, the Balkans, Romania and Bulgaria), meanwhile, space cooling and other energy services are equally important as space heating. Hence, all energy services should be addressed in order to achieve a significant reduction of GHG emissions from buildings [47].

Building concepts and the role of building standards

The path to low carbon or carbon-free buildings is achieved through a combination of technological improvements on the one hand, and standards, labels and regulations (codes) on the other. Techno-economic progress and efficiencies allow for the definition of ambitious standards [which

are often incorporated in regulations later on). And vice versa, ambitious labels, standards and regulations foster the development of more efficient and cost-effective products and services.

Low energy buildings: a) consume around half the heating demand of a house with existing standards, e.g. of Germany or Switzerland; b) the heating demand ranges from 30 kWh/m² year to 20 kWh/m² year.

Passive house buildings: a) are ultra-low energy buildings, as defined by Professors Bo Adamson of Lund University, Sweden, and Wolfgang Feist of the Institute for Housing and the Environment (Institut für Wohnen und Umwelt); b) heating demand shall be a maximum of 15 kWh/m² year and cooling demand also a maximum 15 kWh/m² year. The total primary energy demand allowed is 120 kWh/m² a. The air exchange between the inside and outside shall be of a maximum 0.6 h⁻¹.

Low exergy buildings: a) “low exergy (or LowEx) systems” are defined as heating or cooling systems that allow the use of low value energy as the energy source. In practice, this means systems that provide heating or cooling at a temperature close to room temperature. (LowEx Guidebook); b) this concept promotes the use of heat pumps without specifying a limit for heating demand.

Zero energy buildings: a) buildings that have zero net energy consumption annually, and zero carbon emissions. The building harvests its energy on-site; b) the energy consumption of the building is not zero and is mostly similar to a passive house building, but the annual balance between energy production and energy consumption is zero.

Plus energy buildings: a) have a net production of energy over the year. Energy production from renewable sources is greater than imports from external sources; b) in order to reach this standard, “plus energy” buildings usually have the most efficient electronic devices and good envelope insulation and thus, have a good performance as such.

Retrofit of existing buildings: follow less stringent standards than new buildings and often are implemented with a time lag, i.e. the time set for achieving the same standards as new buildings is shifted.

The European Union has set a target that from 2020 onwards (2018 for offices), all new residential buildings will be passive houses. In the United Kingdom, the government announced in

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(49) The Revised Energy Performance Directive for Buildings EPBD (2002, 2010) obliges member states to draw up minimum standards. These should be applied to all new buildings and to existing buildings with a usable floor area above 1000 m² when they undergo a major renovation.
December 2006 that in 2016, all homes would be Zero-Energy Buildings (ZEB). More member states are expected to define similar goals which in turn will lead the EU to define new goals for the community as a whole ([49]).

Historically, building standards and labels have targeted the energy demand for heating and, sometimes, hot water. However there is a trend to extend coverage to other services such as appliances and lighting ([50]). From 2020 on, all electronic devices will need to fulfill A-class standards to be integrated in passive houses. Lighting shall be provided as far as possible by natural sources and energy-saving lamps. The latter point draws attention to the design of buildings. As crucial as materials may be, the design and orientation of a building contribute significantly to a better use of energy in all parts of the building.

The potential evolution of building concepts can be roughly subdivided into four steps from 2000 to 2050 in Europe, starting with a) an improvement of standards to low energy buildings, b) extend to passive houses, c) zero energy buildings and d) plus energy buildings. For existing buildings, new standards are difficult to implement and a 10-year lag is assumed in order for them to meet required standards (the renovation of existing buildings is not always carried out in time but mostly when they are really obsolete). As a result, the whole dynamic of reaching sustainability in all buildings is considerably slowed because of existing buildings.

In order to comply with future standards, the building envelope and building technologies shall be improved and implemented for new constructions. Passive house standards only allow for a maximum heating demand as well as a primary energy demand, and also set a level for the air exchange rate. To achieve these efficiency levels, all parts of the building need to be considered and designed with great care (for example, thermal properties, size, type and orientation of windows, ventilation system, energy sources used, etc). The technology required to meet future building standards is shown in the graph below. The representation is non-exhaustive and presents only a panel of possible improvements.

### Table 2.3: EU Pathway of building concepts for new and existing buildings

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<tr>
<td><strong>New Buildings</strong></td>
<td>Standards</td>
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<td>Passive energy</td>
<td>Zero energy</td>
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<td><strong>Existing Buildings</strong></td>
<td>Standards</td>
<td>Low energy</td>
<td>Passive energy</td>
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  - as of 31 December 2020 new buildings in the EU will have to consume “nearly zero” energy and the energy will be “to a very large extent” from renewable sources;
  - public authorities that own or occupy a new building should set an example by building, buying or renting such “nearly zero energy building” as of 31 December 2018.

[50] For instance, the new French regulation RT2012 includes hot water, ventilation and lighting.
system. Retrofitting energy-saving technologies, even through simple means such as installing better insulation, will require active decision-making on the part of households.

The household may have to actively intervene in any of these aspects. The building envelope and structure will have to be addressed as part of retrofit programmes, since if the building envelope is poor, measures such as insulation will not prevent heat loss through other parts of the envelope that are not improved. The building technologies required for zero or plus energy houses require localised power production. The plus energy house is also designed to produce energy. This only makes sense if the energy is transmitted into the wider power system. This then requires a new relationship with the electricity transmission and distribution system, where individual houses sell electricity, instead of buying it. Consequently, the household becomes a supplier as well as a consumer in the energy market.

Householders in their homes: from micro energy consumers to micro energy actors

The transition to a low carbon society by 2050 will only be possible if there is a large scale adoption of low energy technologies in both housing and energy use within the home. However, it is not just a matter of building “better” houses. The successful application of the technologies will require changes in household behaviour.

Building concepts which drastically reduce energy demand are passive house buildings and zero energy buildings, while plus energy buildings are designed to produce energy overall. Over the period to 2050, the renovation of existing buildings will form a large part of the reduction in energy demand in housing. While passive house buildings rely on natural ventilation, advanced construction and minimising heat loss, zero and plus energy houses move to concepts where the household actively controls its own energy system.

### Figure 2.50: Technological requirements for meeting standards up to 2030

<table>
<thead>
<tr>
<th>Energy Consumption</th>
<th>Weighted Energy Demand 38 kWh/m² year</th>
<th>Weighted Energy Demand 30 kWh/m² year (Minergie-P)</th>
<th>Very low net annual energy consumption Zero net annual energy consumption Positive net annual energy consumption</th>
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<tr>
<td>Wall insulation</td>
<td>U-value=0.2-0.3W/m²K (SIA 380/1)</td>
<td>U-value&lt;0.15W/m²K Passive house</td>
<td>Vacuum insulation panels Dynamic thermal conductivity</td>
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<td>Windows</td>
<td>U-value=1.3-1.6W/m²K (SIA 380/1)</td>
<td>Triple-glazed windows U-value&lt;0.8W/m²K</td>
<td>Thermo-/Electrochromic glazing Vacuum insulation windows</td>
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<td>Heating system</td>
<td>Renewable Energies Recommended (Minergie)</td>
<td>Renewable energies Compulsory (Minergie-P) HP, PV, Pellets, Wind</td>
<td>Parrafin wax storage tanks District heat pumps</td>
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<td>Ventilation</td>
<td>Heating recovery ventilation system</td>
<td>Air exchange number &lt;0.6/l</td>
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<td>Warm water</td>
<td>Solar thermal water heaters</td>
<td>Heat recovery from waste water</td>
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<td>Lighting</td>
<td>A-class devices Recommended (Minergie)</td>
<td>LED lamps Compact fluorescent lamps [CLF]</td>
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<tr>
<td>Electronic Devices</td>
<td>A-class devices Recommended (Minergie)</td>
<td>A-class devices compulsory (Minergie-P)</td>
<td>Very low stand-by power consumption</td>
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This requires a different legal basis and may also require active decision-making by the household energy system. Smart metering technologies will enable automated operation of the system, but parameters such as the willingness to provide electricity to the grid at times of high demand and reduce the household’s own demand will have to be chosen by the household.

The household may also have to make complex decisions about the use of domestic appliances. For example, the optimal profile of energy supply and demand for the house may require the use of auxiliary heaters and cooling appliances to be temporarily limited for the short periods of time when demand is higher than energy generation and stored energy is limited. At periods of short-term peaks in energy demand in the electricity system as a whole, it may be economically desirable for the house to sell energy into the grid at a high price and delay the use of domestic appliances where the individual household’s demand is not immediate e.g. for laundry washing or dishwashers.

### Housing technologies that will involve changes in behaviour

The Z² approach is applied for zero energy buildings (Zeroenergyhouse, 2009; Fujitaresearch, 2010).

Here are its main behavioural characteristics:

- reduce to a minimum the energy consumption, including the use of passive house technologies;
- produce a maximum of electricity (Photovoltaics, BiPV, local wind turbines, Hydro-electric, etc.) and heat (from solar collectors, heat pumps, passive heating, etc.);
- store the surplus energy for reuse (thermal mass, heat pump, storage tank, etc.);
- zero emissions;
- zero costs of operation.

A fundamental feature of this approach is that power generation is localised. The house generates its own power and this is managed as part of an energy system for the individual household. The household therefore has to take responsibility for the control of energy demand and supply within their own system. While this can be contracted out to an energy services provider who maintains the equipment, the individual household will probably become more aware of energy provision and use as a part of their lifestyle.

With the technologies currently being developed, a zero energy building can become a plus-energy building where there is net energy output. The principle is the same as for zero energy buildings but with even higher performance [51]. This transforms the household into a micro power station. In an energy system with a large number of plus-energy houses, the performance of the whole grid will need to be metered, taking account of the contribution of individual plus-energy houses. This may also involve considerations of managing fault conditions in the grid network, with provision for fall-back and recovery arrangements from fault conditions. Such considerations also require a different form of energy contract for services for the household.

### Renovation of existing buildings

Three standard situations for existing buildings are distinguished. The first is the complete demolition and reconstruction of the existing building. This case is straightforward and does not present a different scenario than for new buildings, since the building can be constructed according to the latest standards. The second option is the retrofit of existing buildings where the envelope remains the same. As already mentioned, restrictions including cost barriers impede full renovation of such buildings. The last option for renovation is the incorporation of prefabricated components such as the roof. Prototypes can be built according to the latest standards. Usually the pitch roof of the existing building is replaced by a prefabricated model with a flat roof and much better insulation. Of course, this measure is not always feasible.

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Renovation undertaken by a private household means that the household becomes actively involved in decision making about energy in a different way – in improving and investing in the home. The complex set of decisions involves both lifestyle and economic factors. Large scale renovation is a major expense for most families, so the desired features of the renovated house have to be matched against the resources available. This also includes the relevant building standards as well as any government subsidies. Decisions about renovation involve a much more intensive consideration of the features of the house and its performance as an energy system than for the day-to-day operation of the household’s energy services.

**Use of renewable and recyclable materials**

A further area of decision making where household behaviour could change is in the adoption of recycled and renewable materials. If a renewable, recyclable and healthy insulating material has similar thermal properties as another, it should prevail in the market (for example wool insulation, chipboard, straw, cork). In tests into whether straw insulation presents a high risk of flammability, it appears that straw bales, when compressed and sealed with plaster, resist combustion better than foam insulation.[52] (52) Straw insulation for the Home – Green Building Elements, http://greenbuildingelements.com/2009/03/09/straw-insulation-for-the-home

**Smart windows (Electrochromic windows)**

Electrochromic windows, like thermochromic windows, are constructed from a material that changes from transparent to opaque above a given temperature. They can be programmed to change state at a certain solar intensity, giving the household control over the amount of light in a building on sunny days. In central and southern European countries, this can be especially useful during the day to avoid overheating of the interior and thus can save cooling energy. If Europe experiences more hot periods due to climate change by 2050, the area of application of this technology will also increase.

**Water collection and treatment**

Another area where household attitudes may change is the use of water. In terms of water supply, rainwater can be used for many non-drinking purposes, like flushing toilets, washing machine, car washing, garden sprinkler, etc. A tank of the same design as the drinking water tank is installed underground and connected to the house. Quality control of the water must be undertaken before the rainwater can be used. The principle of decentralised provision can be further extended to grey water collection. Grey water collection uses water from the bath, shower and washbasin for further purposes, like toilet flushing or gardening water, after any required treatment. These technologies involve a further fundamental shift in attitudes similar to that in energy, away from central provision of the service to household provision.

2.1.2 | Innovations in mobility

In *Part 1*, all investigations into the dynamics of the need for energy services were based on Zahavi’s proposition that time spent travelling remains constant everywhere. This proposition is increasingly being challenged, due to the lack of clear understanding up until now of the reasons behind the observed stability over recent decades almost everywhere, and of the meaning of an increase in the transport time budget (TTB) observed recently in some countries. Research carried out in the PREDIT programme into sustainable mobility shows that changes in TTB may have major consequences for the development of mobility, and thus for related energy service needs[53]. A change in the TTB

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would also affect other areas of the time use structure, and therefore the need for energy services in other socio-cultural functions.

The main question is: to what extent should the stability in the TTB observed be understood as a fundamental characteristic of human behaviour or as a consequence of a particular energy technology paradigm (oil-based), in which the cost of speed has always evolved more slowly than affluence (and thus also the value of time)?

This question is currently being addressed in the PACT research project [54], through a spatial assessment of mobility within and outside urban areas, and in relation to the distribution of housing and other services in urban areas. Areas of study include how locations impact daily mobility programmes and daily TTB, according to transport services availability; the trade-off between daily mobility and weekend and holiday mobility; and the trade-off between time spent in self-fulfilment (leisure, especially) and travelling.

Developments below are based on the results of the PREDICT research into sustainable mobility and are relevant for the EU as a whole, while the figures provided for illustrative purposes refer to France alone.

Innovations in vehicle technology, motorisation, motor fuels and services

Car propulsion can be based on three core technologies: the internal combustion engine (ICE), battery electric technology, and fuel cell technology. The ICE is the most widely deployed technology at present, accounting for most of the 700 million vehicles worldwide today.

With growing constraints on CO₂ emissions and oil availability, the sustainability of ICE technology has increasingly been called into question. But there is still room for valuable research into improving its current form, and as such it is too early to dismiss it as a technology of the past. Also new fuels are coming to replace gasoline and diesel, which might give a second life to the ICE. These fuels are natural gas, biofuels made from biomass and synthetic fuel made using coal, an abundant energy source for which the Fischer-Tropsch industrial process is well known.

However, new technologies using radically new energies sources and carriers are also emerging. These are based mostly on batteries that store energy in an electrochemical device, and on fuel cells that convert hydrogen into electricity. These technologies are both competitors and allies: competitors, because if one of them achieves a breakthrough, it will make it more difficult for the others to play a significant role on the market; allies, since all are propelled by an electric motor, it is just the way the electricity is produced on-board that differs.

Figure 2.51: The 3 technologies for automotive


In the common sense, HEV and PHEV are hybridized with the ICE. (BEV: Battery electric vehicle; HEV: Hybrid electric vehicle; PHEV: Plugin hybrid electric vehicle).
Besides these technologies, a cross-cutting approach is trying to extract the best of each: the hybrid system. Hybrid cars are generally propelled by two motors instead of one, and some also have two energy sources. Hybrid vehicles can get the most out of each tank of fuel and are more efficient: their low-efficiency engine carries the vehicle (in motorway driving, in particular), while the high-efficiency engine adds power when the car accelerates (in urban settings). The system's sophistication also makes it costly, however, and therein lies the weakness of hybrid vehicles.

The battery electric vehicle (BEV)
The battery electric vehicle uses chemical energy stored in rechargeable battery packs. As with other electric vehicles, BEVs use an electric motor instead of an internal combustion engine for propulsion.

The benefit of battery electric vehicles is that they have no need for the entire internal combustion engine system, drive train or fuel tank, giving a saving of up to US$3,000-4,000. What they do require is a large battery capacity and a powerful motor, to provide the peak power that drivers expect.

Their cost depends on the cost of the batteries and few electric cars are currently on the market. However, many car-makers have announced that they will launch battery electric vehicles for 2010 and later.

Battery vehicle and renewable electricity have interesting synergies, since the deployment of batteries for cars could offer useful storage capacity for the grid, and thus a potential solution to the intermittence of renewable power sources (wind, solar), and a way to better manage the load curve. The electric current could even flow both ways, enabling the car fleet to feed the grid. If it is assumed that 2 million battery vehicles are connected to the grid at any time, and each car has a power of 50 KW, that represents 100 GW available instantly to the grid.

The hydrogen fuel cell vehicle (FCV)
A fuel cell is an electrochemical conversion device. It produces electricity from fuel which is normally hydrogen, and an oxidant which make the reaction possible. Fuel cells are different from electrochemical batteries in that they consume fuel, which must be replenished, whereas batteries store electrical energy chemically in a closed system.

Hydrogen does not emit CO₂ at the user’s end. As electricity, it is an energy carrier that can be produced from a wide variety of primary energy sources, including non fossil fuels. Fuel cells are about 50% energy-efficient (55% for a fuel cell and 90% for the electric motor), compared to 20-25% for an ICE. Fuel cells produce only water and make no noise when running.

But hydrogen, unlike liquid fuels, is not easy to transport, distribute and store (low volumetric density), especially in vehicles where space is limited. Fuel cells are also very expensive and certain technical barriers need to be lifted before mass deployment is possible. Hydrogen also requires specific safety procedures compared to other common fuels.

Biofuels and synthetic fuels for ICE vehicles
Biofuels can be defined as renewable, since they are obtained from recently deceased biological material.

Synthetic fuels are defined, not by their original feedstock, but by their characteristics and the process used to make them. They can be obtained from a wide range of raw materials, such as coal (CTL), gas (GTL) and biomass (BTL), but also other solids such as plastics or rubber waste. Produced mainly using the Fischer Tropsch conversion process, they rely on significant chemical plant infrastructure, and can thus be produced either in big or small plants, unlike biofuels (small plants).

Unlike the two previous technologies, biofuels and synthetic fuels do not require a radical shift in engine technology, just small adjustments to the ICE. The main change is the fuel used on board.
They also use, more or less, the same delivery infrastructure as oil. No major investments have to be made in service stations, as most could be re-used. Moreover, research into the ICE will also apply to them, which is very valuable as car-makers have plenty of expertise in the technology. Under certain conditions, biofuels can emit very low CO₂ emissions over the whole cycle.

Biomass used to produce biofuels might remain difficult – and ultimately costly – to collect. Biofuels are not especially energy-efficient as they work in an ICE, which is only around 20% efficient. This is low compared to the electric motor, for instance. Biofuels also raise the risk of deforestation in some countries, which would be a major problem as it would worsen GHG emissions. There is a real risk that some states might opt for short-term revenue from biofuels and deforest their land.

Synthetic fuels have more or less the same characteristics if made from biomass (BTL). But for those made from fossil fuels, the amount of CO₂ released into the atmosphere will not be counterbalanced by the growth of new biomass, and so will imply a positive net emission of CO₂, even with carbon, capture and storage (CCS).

**Benefits to consumers**

Biofuels and fuel cell vehicles offer greater benefits to consumers as they are multi-purpose vehicles which can be used in almost any circumstances. On the contrary, the user of an electric vehicle will have much lower autonomy [around 100 to 200 km].

*Figure 2.52: The hybrid vehicles*

- **Plug-in hybrid** is a vehicle that can run just on the engine, just on the batteries, or a combination of both. Full hybrid can also do it, but only for few hundreds of meters.
- **Electric vehicle** do not have the *Energy adaptation* device since they rely on one motor and one energy. But the electric motor must be more powerful and the battery pack is more important.

**Hybrid, an appealing intermediate technology**

A hybrid vehicle uses two or more distinct power sources to propel the vehicle. The term most commonly refers to hybrid-electric vehicle (HEV) which includes an internal combustion engine (ICE) and an electric motor. However, it might alternatively include ICE and a hydraulic motor, for instance. Four functions are associated with hybrid technology:

- **EV Drive**: The combustion engine is off and the battery provides electrical energy to power the motor.
- **Energy adaptation**: When the ICE is not at an optimum point [accelerating...], the battery provides/recover electrical energy to/from the thermal motor.
- **Regenerative braking**: A regenerative brake is a mechanism that reduces vehicles speed by convert some of its kinetic energy into another form of energy that can be stored.
- **Engine stop and start**: The engine stops when the car stops (e.g. traffic-jam) and/or when the car brakes.

Six types of vehicles correspond to these functions, five of which are hybrid while the sixth is a pure electric vehicle (which has already been described):
Full hybrids have an internal combustion engine and all the components of a hybrid system, including the electric motor. Their energy and CO₂ performances are good, but are costly, even if the battery pack is limited. The electric propulsion of a full hybrid is limited.

Plug-in hybrids are the most sophisticated cars in term of function. They have the same basic components as the full hybrid, plus more battery capacity. This makes it possible to drive several kilometres with the electric motor. Batteries can be recharged from the grid or from a home-based electricity generation system. The number of components in those cars is significant (two motors and two external sources of energy). Well-suited to both urban and motorway driving, they are expected to be the most expensive cars.

Hybrid cars available on the market at present are mainly micro-hybrids and non-pluggable full-hybrids.

European car-makers could quickly adopt the “Engine stop” system, as the device is affordable and potential fuel savings are significant. In contrast, they are less interested in the full or plug-in hybrid, due to cost. This could change, however, if the oil price increases.

Technology innovation and changes in mobility needs

Around 20% of journeys by car are long trips, of over 200 km in one day. Such trips are made only a few times per year. However, customers want vehicles suited to all kinds of needs (multi-purpose vehicles), including both short and long trips.

Short trips
If oil becomes more expensive and CO₂ emissions from transport are further restricted, the battery electric vehicle might be the most cost-effective for short trips. As European car-makers have announced some launches of battery electric vehicles for 2010 and later, there is a good chance that the future urban car will be a battery electric vehicle.

Long trips
For longer trips, the fuel cell and biofuels are better technical solutions. But the range extender could change the picture. This is a small on-board electricity generator that adds power to a basic electric vehicle. This device “sustains” vehicle operation beyond the range provided by the batteries, which could prove useful when the batteries available do not offer the range necessary for market acceptability. In a post-carbon world, the range extender could rely either on a hydrogen and fuel cell system, or on biofuels.

Multi-purpose vehicles versus dedicated vehicles
In Europe, roughly 30% of the distance covered by cars is in urban areas, 50% around cities, and 20% for long trips. Approximately half of motorised households own just one car which has to be multi-purpose, and the other half owns two or more cars, the second of which is used mostly for (short distance) everyday trips and does not therefore have to be multi-purpose. These figures give a first idea of the market boundaries for each technology.

Pure ICE vehicle: the pure ICE vehicle, whose market share accounts for 100% today, will lose influence over the coming decades, challenged first by hybrid vehicles and then other technologies. The current ICE might be totally replaced by 2050.

[56] The “stop and start” device is called “micro hybrid”. In fact, this name is not so appropriated as those vehicles do not have two motors and do not have the hybrid function.
Hybrid vehicle (1st generation): the first challenger will be the hybrid vehicle (1st generation). The ICE will still be a part of this vehicle, but the battery will provide electrical energy to the thermal motor thanks to the electric motor. Accordingly, the energy consumed will be a mix of fossil fuels and electricity. At the beginning, fossil fuels will remain predominant, but gradually, as plug-in hybrids come on the market and batteries become cheaper, electricity might become an important energy carrier.

Pure electric vehicle: pure electric vehicles are about to be deployed on the market. They will be targeted at urban use, and because this represents a large part of overall mobility they might significantly penetrate the market. Battery costs will be key to their success.

Hybrid vehicle (2nd generation): The second generation of hybrid vehicle dispenses with fossil fuels, which are replaced by biofuels or hydrogen. Biofuels and hydrogen can store a considerable amount of energy and enlarge the range of the pure electric vehicle. This vehicle could also be a battery electric vehicle, equipped with a range extender running on biofuels or hydrogen. Hydrogen-fuel cells could start being deployed around 2030.

Technologies for other transport modes
Here is a very quick review of how new technologies may impact other transport modes in a transition towards a low carbon world:
- scooters might be propelled by batteries. Electric bikes and electric scooters should merge;
- taxis, public buses and light trucks might be propelled by battery; hydrogen and fuel cells might be an alternative option;
- heavy trucks may be propelled by the ICE using biofuels, or by hydrogen and the fuel cell, as they need a lot of energy on board;
- planes might be powered with bio-jetfuels. Hydrogen might also be an option for aircraft, but as space is limited, biofuels should be more competitive;
- boats might be propelled by hydrogen and fuel cells, as hydrogen can easily be stored in the boat.

Conclusions: battery technologies more and more critical
On the one hand, the ICE may remain competitive for a long time, benefitting as it does from decades of research and experience, and because it relies on a fuel that has many advantages for the car industry: abundance of fossil fuels, density of these fuels, ease of fuel storage in vehicles where space is limited, and so on. On the other hand, the ICE may lose its influence sooner than anticipated because of shifts in market conditions (increase in oil price) and policies (more regulation/taxation on CO\textsubscript{2} emissions).

In the latter case, the battery electric vehicle may be the first technology ready for mass deployment. Recent announcements from the car industry suggest that the technology will be ready for deployment in under five years. This may occur thanks to battery technology breakthroughs (the new generation of lithium-ion battery is twice as good as the previous one based on nickel), and also due to public support, as the vehicle has the potential to emit very little CO\textsubscript{2}.

Of course, the drawbacks of battery electric vehicles should not be under estimated, especially their limited range. It will not be possible to use a battery electric vehicle for trips over 200 km. And because half of all motorised households have just one car, the market share of this technology might remain low.
In this perspective, the critical question for the electric vehicle is how to bring more energy on board, to satisfy customers who want to make longer trips. The range extender device might be a good solution, since it “sustains” vehicle operation beyond the range provided by the batteries, which might be a condition for large market acceptability.

To sum up, three “electric” solutions can be considered as possible candidates to challenge the ICE vehicle:

**Figure 2.54: Electric solution as alternatives to ICE**

<table>
<thead>
<tr>
<th>Solution 1</th>
<th>Solution 2</th>
<th>Solution 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Short trips</strong></td>
<td><strong>Short trips</strong></td>
<td><strong>Short trips</strong></td>
</tr>
<tr>
<td>Fuel</td>
<td>Batteries</td>
<td>Batteries</td>
</tr>
<tr>
<td>Motor</td>
<td>Electric</td>
<td>Electric</td>
</tr>
<tr>
<td><strong>Long trips</strong></td>
<td><strong>H₂</strong></td>
<td><strong>Biofuel</strong></td>
</tr>
<tr>
<td>Fuel cell</td>
<td>ICE</td>
<td>Current ICE</td>
</tr>
</tbody>
</table>

The role of technology for the energy and environment transition if mobility trends do not change

*Part 1 showed that for the fossil fuels and nuclear paradigms, neither would require a change in transport system organisation, just greater or lesser changes in road transport technologies (i.e. more or less electric or hydrogen technologies). This suggests that the continuation of the fossil fuel paradigm or the transition towards a nuclear one do not necessarily imply a change in the general conditions that make Zahavi’s proposition true for the coming century.*

The consequence of Zahavi’s proposition for the need for energy services in the EU up to 2100 has been investigated by VLEEM (Part 1). How these needs can be supplied, with what consequences as regards energy and CO₂ emissions, and how this is compatible with a transition towards a low carbon future will be investigated below, for the period up to 2050.

**Speed at the core of the transport system in the current mobility trends: the Pegasus scenario**

Recent research shows that speed is the key driver of transport developments, both for people and freight, as well as the long-lasting and fairly stable statistical correlation between speed and GDP. The values of time and of goods, both related to GDP, are at the core of this correlation [56].

The “PEGASUS” scenarios investigated in the PREDIIT research study of sustainable mobility assume that this correlation continues over the coming decades.

The consequence of PEGASUS scenarios is a continuous modal shift towards fast modes such as planes and high-speed trains for long distance trips, and a predominance of rapid infrastructures.

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[road and rail] in urban and peri-urban areas. PACT research findings suggest that this would favour further concentration of people and activities around big core cities, and city networking.

Below are the main findings of the PEGASUS scenario as regards the development of mobility and how the need for energy services is fulfilled. Although the numbers refer more specifically to the French case(57), the conclusions remain valid for most EU countries.

**Passenger speeds and modal split**

The average speed of passenger movement is expected to grow by 22 % from 2000 to 2050. Over the same period, the average speed of car journeys is expected to increase by less than 16 %, because of the structure of these trips by type of service and the speed limits [mandatory or “natural”] for the various services. Taking into account the decreasing share of slow modes in the modal split, the average speed of journey by public transportation has to increase by 20 % to cope with the average speed increase.

In urban and peri-urban areas, the average speed of car trips would grow by 26 % from 2000 to 2050, while its share in total mobility services would decrease from 90 % (2000) to 72 % (2050); the average speed in urban areas for all modes [including soft modes] would increase by 25 %. This is consistent with more concentrated urbanisation around core cities and rapid road infrastructures, but also increasing density.

For regional trips, cars would continue to increase their market share, from 83 % (2000) to 85 % (2050), with an average speed increase of 17 %. For long distance trips, the average speed of car trips would increase by 5 % [close to saturation].

**Passenger traffic**

Passenger traffic would increase by 42 % between 2000 and 2050 in the PEGASUS scenarios, while the population increases only by 13 to 16 %.

The car traffic in passengers-km [passenger mobility by car] is not expected to increase dramatically (7 %) in this scenario [and even decreases by person], suggesting some saturation in the use of cars. But the car vehicle-km on roads is expected to grow much more (44 %), showing a significant drop in car efficiency (as measured by pkm/vkm). Two reasons explain this decrease in the average load factor of cars:  
- a strong rise in the number of households with one or two persons;  
- a strong rise in the proportion of urban, peri-urban and regional trips by car [where load factors are lower than on long distance].

The bulk of the passenger mobility increase (+240 %) is thus expected to be met by public transport, in particular by very fast modes [planes, high speed trains] for long distances. Air traffic is expected to be multiplied by a factor of two; high-speed trains by a factor four.

In urban areas, passenger mobility is expected to grow by 37 %, but only 6 % for private cars for reasons explained above [concentration around core cities and speed increase], while PT traffic would be multiplied by a factor 4, and slow modes by a factor 2.

In peri-urban and regional areas, cars are expected to bear the bulk of the increase in mobility needs (+65 % increase in passenger traffic by car).

The reverse is true for long distance trips, where cars are challenged by planes and high-speed trains, and passenger traffic by car is expected to fall in absolute terms, by 29 %.

**Technologies for mitigating CO₂ emissions**

We have already looked at the potential of three main technology clusters able to mitigate direct CO₂ emissions for road transport up to 2050: advanced ICE [internal combustion engines], electric-battery and hybrid bi-energy, fuel cells with hydrogen.

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Finally, addressing the CO₂ emissions problem while retaining historic mobility trends would not solve but worsen other sustainability dimensions, including noise, congestion and environmental quality.

**Decoupling speed from GDP to break mobility trends**

The PEGASUS scenario shows that if no change occurs in how the need for energy services is fulfilled, the speed and magnitude of the transition towards low carbon economies is entirely dependent on the technologies likely to be developed within the paradigm, and the speed at which they will be developed. As shown by the PREDIT research on sustainable mobility, this may conflict with more stringent constraints from the climate or oil resource sides, or with more ambitious policy objectives, such as “factor 4”[58].

In this case, a change in behaviour will be necessary to mitigate the growth in mobility without reducing GDP growth, which means “decoupling” the rise in the average speed of people and goods from GDP. This is the core assumption of the “CHRONOS” scenarios investigated by the PREDIT research study on sustainable mobility.

**Policy instruments to decouple speed from GDP**

Speed could be decoupled from GDP with the combination of two policy instruments: speed regulation and speed pricing. Speed regulation would focus mostly on road transport, and contribute to reducing the average speed on all types of road. Speed pricing is mostly designed to reduce the attractiveness of high-speed road infrastructures and air transport; more generally, it is driven by the principle of making the price of speed increase faster than average affluence.

In the CHRONOS scenarios, it is assumed that both instruments are tailored so that the average elasticities of passenger and freight speeds to GDP come to zero.

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[58] Reduction of the CO₂ emissions by a factor 4 between 1990 and 2050.
For passengers, the context for speed development in the CHRONOS scenario is radically different from that experienced in recent decades, raising the question of the validity of the Zahavi’s proposition. Two additional assumptions have therefore been introduced to explore a possible increase in transport time budgets (TTB): the social preference for mobility is mostly unchanged, people accept that they will spend more time travelling on the condition that this time offers additional utility. In other words the main driver of passenger mobility switches from speed to time.

For freight, the overall traffic (mobility requirement) is still driven by GDP, but the average speed ceases to increase, as the cost of going faster rises at the same rate as the value of the ton transported.

**Modal shifts for mitigating CO₂ emissions**
Reducing average speeds on roads and making high-speed road and air transport much more expensive is expected to drive people to choose faster or cheaper modes of transport, mostly by rail or in dedicated road lanes, if those are available and of equivalent quality. Indeed, as shown by micro-economic analysis (59), modal choice results from a trade-off between time and money: for the same price, faster modes are preferred, and for similar speeds, cheaper modes are preferred.

In most cases, rail or dedicated road lanes are more efficient from an energy viewpoint, consuming much less energy and emitting much less CO₂ per passenger-km than private cars or planes. This is also true in most cases for freight transport. Therefore, the main challenge in the CHRONOS scenarios, in order to mitigate energy and CO₂ emissions, is to offer passengers and freight as much rail services and dedicated road lanes as demanded.

These are the main findings of the CHRONOS scenario as regards developments in mobility and how energy service needs are fulfilled, and the resulting modal shift (numbers refer to France, but conclusions remain valid for most EU countries).

**Passenger speeds and modal split**
The average speed of passenger movement is kept constant up to 2050, while the average transport time budget (TTB) is expected to increase by 20% over the period. Because of the change in the structure of mobility services, if the average speed remains constant, the average speed of car journeys has to fall by around 6 km/h, leading to a 13% drop in the annual distance covered by cars, compared to PEGASUS scenarios in 2050. Meanwhile, the average speed of public transport journeys has to increase by 2 km/h to cope with the average speed stability.

In urban and peri-urban areas, the average speed of car trips would still grow slightly (10%) from 2000 to 2050, while its share in total mobility services would decrease from 90% (2000) to 80% (2050); the average speed in urban areas for all modes (including soft modes) would remain constant. This is consistent with an urbanisation giving more importance to small and medium-size cities which are not just satellites of big core cities.

For regional trips, cars would continue increasing their market share, from 83% (2000) to 85% (2050), but with average speed falling a little (2%) compared to public transport. For long-distance trips, the average speed of car trips would decrease sharply [-20%], while its market share would drop to 15%.

For long-distance trips, the share of private cars would decrease a lot (no more than 15% in 2050) under the combined pressure of more stringent speed limits on motorways (100 km/h) and an abundant and competitive supply of high speed trains.

**Passenger traffic**
Passenger traffic would increase by 35% between 2000 and 2050 in the CHRONOS scenarios, while the population would increase only by 13-16%.

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(59) Micro-economic analysis is usually formalized in transport models with generalized cost functions that account for the value of time.
Car traffic in passengers-km (passenger mobility by car) is expected to decrease slightly (-7%) in the CHRONOS scenario (further decreasing by person). But the car vehicle-km on roads is expected to grow (+28%) because of a significant drop in the efficiency of cars to supply mobility (as measured by pkm/vkm). This is due to a decline in the average load factor of cars as in the PEGASUS scenario.

The increase in passenger mobility is thus expected to be supported entirely by public transport, which could see an increase between 2000 and 2050 of up to 270%. Air traffic is expected to evolve in a range -30% to +60%, depending on the development of high-speed rail transport, which is itself expected to grow enormously, by a factor of between 5 and 8.

In urban areas, passenger mobility is expected to grow by 37% (as in the PEGASUS scenarios): private car use would increase by 18%, public transport traffic would increase three-fold, and slow modes by a factor of two.

In peri-urban and regional areas, cars are expected to assume the bulk of the increase in mobility needs (+65% in passengers traffic by car).

The situation is reversed for long distance trips, where cars can no longer compete with air transport and, mostly, high speed trains: passenger car traffic is expected to decrease in absolute terms by 70%.

Findings for the transition towards low carbon economies

The first conclusion of the CHRONOS scenarios is that, given a rather optimistic evolution of transport technologies towards plug-in hybrids and electricity, it is possible to reduce total CO₂ emissions from transport (direct and indirect) by a factor of four simply by halting the increase in average speed through regulatory and economic measures.

But the second conclusion is that, to reach this factor of four reduction, a huge development of surface public transport, in particular high speed trains, would be necessary, requiring extremely high investment and generous public subsidies, and risking severe public acceptance problems.

Decoupling totally mobility from GDP

CHRONOS scenarios show that given the right constraints and policies, advanced technologies and speed limits can deliver CO₂ emission cuts. Nevertheless, the possibility that the transport time budget might expand as well as the need to shift traffic away from roads depends on a huge development of new rail and dedicated road lane infrastructure and services, which might be difficult to finance and which may have severe drawbacks as regard land-use and noise. As shown in the table below, investments for rail and public transport would amount to roughly 30 billion euros per year between 2000 and 2050 in CHRONOS scenario, compared to four billion in 2007.

<table>
<thead>
<tr>
<th>Billion of EUR</th>
<th>Mode</th>
<th>2050 Pegasus</th>
<th>Per annum</th>
<th>2050 Chronos</th>
<th>Per annum</th>
<th>2050 Hestia</th>
<th>Per annum</th>
<th>Year 2007</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investments</td>
<td>Road</td>
<td>1043</td>
<td>21</td>
<td>384</td>
<td>8</td>
<td>140</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Rail</td>
<td>747</td>
<td>15</td>
<td>1529</td>
<td>31</td>
<td>992</td>
<td>20</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Public Tm.</td>
<td>137</td>
<td>3</td>
<td>74</td>
<td>1</td>
<td>77</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Others</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1927</td>
<td>39</td>
<td>1987</td>
<td>40</td>
<td>1209</td>
<td>24</td>
<td>18</td>
</tr>
</tbody>
</table>

H. G. Lopez-Ruiz 2009  
Note: – means not applicable
To mitigate these consequences, the key policy challenge is to avoid the rebound effect of speed control on the transport time budget: in other words, not only to decouple GDP from speed, but also from mobility as a whole. This is the additional core assumption of the “HESTIA” scenarios investigated by the PREDIT research.

**Policy instruments for decoupling mobility from GDP**

The “decoupling” issue has been investigated in a number of studies[^60]. They appear to conclude that, despite a strong historical correlation between mobility and GDP, decoupling could be achieved with active policies and no significant drawback for economic development.

From a policy viewpoint, this means basically imposing speed limits and at the same time preventing an increase in the TTB, while at the same time encouraging people’s expectations as regards accessibility to opportunities. This implies that people can find at a shorter distance, with lower speeds, the same opportunities as they would have found further away and faster in “business-as-usual” development. This is mostly a matter of land-use.

In “HESTIA” scenarios investigated by the PREDIT research, this has been captured keeping the TTB constant, while assuming elasticities of speeds to GDP equal to zero.

In these scenarios, Zahavi’s proposition remains valid in the coming decades, but more as a result of dedicated land-use and transport policies than the spontaneous expression of social preference. These policies organise restrictions to the development of mobility needs, giving priority to accessibility and gaining public support. This scenario takes place in a new paradigm where the value of “having more [satisfaction] with less [consumption]” substitutes for the current belief that “more [consumption] gives more [satisfaction]”. To some extent, this is not far from the philosophy of the renewables paradigm introduced in Part 1, where the objective function is to increase the utility and/or activity level provided by one unit of energy as much as possible, rather than increasing the utility and/or activity level by the number of energy units[^61].

**Land-use planning for mitigating CO₂ emissions**

Land-use planning for mitigating CO₂ emissions, as far as transport is concerned, means three things:

- reducing journey distances in urban areas by a spatial reallocation of housing and services: this is a matter of construction rights, land taxation and location of public services;
- reducing average distances between urban areas, between urban areas and industrial facilities and between industrial facilities, by expanding consumption opportunities in urban areas, rebalancing industrial economies of scale and transport costs, and by pricing speed (in other words, changing the distribution of long distance trips in favour of shorter distance trips);
- taking advantage of solar radiation and PV electricity to change people’s expectations as to the average autonomy of road vehicles.

The options and conditions for reducing travelling distances in urban areas by spatial reallocation of housing and services are currently being investigated in the PACT project[^62].

What follows are the main findings of the HESTIA scenario as regard the development of transport, how the need for energy services is fulfilled, and the resulting modal shift (numbers refer to France, but conclusions remain valid for most EU countries).

Passenger speeds and modal split
The average speed of passenger movement, as well as the transport time budget (TTB), is kept constant up to 2050. Because of the change in the structure of transport services, if the average speed remains constant, the average trip by car has to decrease by around 18%, prompting a related decline in the annual distance driven by cars of roughly 26%, compared to PEGASUS scenarios for 2050. As a consequence, the average speed of journeys by public transportation has to increase by 22% to cope with the average speed stability.

In urban and peri-urban areas, the average speed of car journeys would grow a little (10%) from 2000 to 2050, while its share in total mobility services would decrease from 90% (2000) to 73% (2050); and the average speed in urban and peri-urban areas for all modes [including soft modes] would still increase a little (10%). This is consistent with a re-densification of suburbs around big core cities.

For regional trips, the market share of cars is expected to fall slightly, from 83% (2000) to 80% (2050), along with a decline in average speed of roughly 10%.

For long distance trips, the share of private cars would decrease sharply (no more than 24% in 2050), but less than in CHRONOS scenarios. Again this will be due to the combined pressure of more stringent speed limits on motorways (100 km/h) and of the abundant and competitive supply of high speed rail travel.

Passenger traffic
French passenger traffic would increase in the HESTIA scenarios along the same path as the population: 13 to 16%.

Car traffic in passengers-km (passenger mobility by car) is expected to decrease sharply (-22%) in the HESTIA scenario (further decreasing by person).

Public transport is expected to plug the gap, supporting the rise in net passenger mobility and the decline in car traffic. The overall increase of public transport between 2000 and 2050 could reach almost 220%. Air traffic is expected to decrease by 40%, while high speed trains are expected to grow significantly, their traffic being multiplied by a factor of five.

In urban areas, passenger mobility is expected to grow by 28% (lower than in PEGASUS or CHRONOS scenarios), while trips by private car would remain constant at the 2000 level. Journeys by public transport would be multiplied by almost four, and slow modes of transport by more than two.

In peri-urban and regional areas, cars and public transport are each expected to absorb roughly half the increase in mobility needs.

For long distance trips, where cars are barely able to compete with high speed trains, car passenger traffic is expected to decrease in absolute terms by 60%.

Findings for the transition towards low carbon economies
The first conclusion of the HESTIA scenarios is that it is possible to reduce total CO₂ emissions from transport (direct and indirect) by a factor of four, by combining technological improvements towards plug-in hybrids and electricity and controlling the increase in travel speed and land-use management through regulatory and economic measures.

The second conclusion is that reducing emissions by a factor of four in this way would probably be least costly for the public authorities and most acceptable for the public. To be effective, however, there would need to be changes to land-use taxation and an extension of carbon quotas to some transport activities, in order to support the necessary changes in land-use.
2.2 | Chapter 2

Energy environment transition and land-use issues

At a time of increasing concern about the relationship between man and his environment, land-use is at the heart of the debate about energy and climate change.

The first major issue is urban sprawl. Cities have grown rapidly in the age of cheap oil: they consume 75 percent of the world’s energy and emit 80 percent of greenhouse gases. Cities are presently growing globally by 2 percent per year (over 3 percent in less developed regions and 0.7 percent in more developed regions), while rural areas have levelled out and in many places are declining. For the first time, more than half of the world’s population lives in cities, and it is estimated that by 2030 the number of city dwellers will reach five billion, or 60 percent, of the world’s population\(^6\). In the case of Europe we expect 83 percent of people to live in cities in 2050 – almost 557 million people\(^4\).

The second major issue is competition for land. The European Environment Agency has recently studied various land-use scenarios for Europe, taking account of economic, environmental and social issues, that will be developed here\(^5\). Changes to energy supply solutions will be necessary to meet the challenge of the post-carbon society, so the way that different renewable energy sources compete with or complement other land-uses in long-term energy scenarios will be critical.

This chapter is mainly based on the preliminary outcome of the ongoing European PACT research project\(^6\).

2.2.1 | Human settlements and urbanisation: moving towards low carbon cities

Rethinking how we create our built environment is critical to reducing our dependence on oil and minimizing our carbon footprint. The bulk of the change towards a post-carbon society needs to come from cities and their government and constituencies (companies, citizens, stakeholders). National governments can do a lot to help or hinder these efforts, but really important initiatives have to begin at the city level because of the variation in how cities cope with issues within any country or region.

A simple way to represent the ongoing urbanisation process is to show the possible patterns of population concentration, as in the figure below:

*Figure 2.55: Urban structure by number of centres and level of concentration*

When the population of a country or world region increases, we see two concomitant effects in the spatial distribution of the population: an increasing number of population centres and an increasing concentration of the population within those centres. Depending on local historical and geographical contextual factors – which should be analysed on a case by case basis – the


\(^6\) Pathways for Carbon Transitions, www.pact-carbon-transition.org
relative strength of the two effects may be different and create different urbanisation patterns, i.e.:  
- mainly dispersed, when the population is distributed between a large number of small centres;  
- mainly concentrated, when the largest share of the urban population is concentrated in one large monocentric city;  
- polycentric, with growth concentrated in a number of centres of different dimensions, forming a network of cities.

The key factors behind the different forms of settlement have been analysed in the PACT project, focusing on the nexus between the spatial distribution of:  
- population (where people live: houses);  
- consumption opportunities (where people consume private and public goods);  
- production opportunities (where people produce).

Two factors have been identified to describe dominant lifestyles and urban forms – the time-speed factor and the density factor – illustrated by the 2x2 grid below:

The time-speed factor makes a distinction between “doing things fast” or “slow”

“Fast” production or consumption activities require that a large number of products are made (or a large number of consumption opportunities exploited) in a single unit of time, by:  
- concentrating production, distribution or service activities in large units that exploit economies of scale; and  
- connecting these units to local and global markets with fast transport and information networks – to transfer people (workers, customers), goods and information in and out – as well as with efficient energy infrastructure, water infrastructure and waste collection services to satisfy their highly concentrated needs.

This is the paradigm of modern globalised economies and lifestyles, which require high amounts of energy per capita, high productivity per worker, high capital intensity and global markets to be sustained. In other terms, doing things fast implies doing them on a large scale, consuming large amounts of energy and natural resources, in a way that is high capital/low labour intensive, and dependent on global markets. The high productivity per worker and speed of the production or consumption processes is the result of an increasing process of mechanisation/automation, e.g. by means of automatic tellers in the banking sector or other do-it-yourself devices in the service sector. The mechanisation of agriculture, coupled with the use of fossil-fuel fertilisers, is perhaps the most important example of how the speed imperative lies behind increasing urbanisation, as it pushes people previously employed in agriculture out of rural areas to find new urban jobs.

“Slow” production and consumption activities do not require a concentration of large production, distribution or service units, as for them it is usually sufficient and more effective to have smaller organisational units, using lesser amounts of extra-somatic energy per capita, with lower capital intensity and productivity per worker – i.e. more labour intensive processes – and greater reliance upon local resources and
markets. The need for a fast transport infrastructure is also reduced – as it is the need for energy, water, waste disposal, etc. – due to the smaller scale of production and consumption processes, and the greater reliance upon local resources of labour, energy etc. In other terms, doing things slowly implies doing them on a small scale, consuming low amounts of energy and natural resources, of low capital/high labour intensity, and dependent on local markets. This was the paradigm of the pre-industrial world, which still dominates in less developed and traditional economies. It is a paradigm that is being recovered to some degree in post-industrial economies, where people are choosing to support more environmental friendly and socially cohesive production schemes. Organic farming, for instance, and the production of local food within or in the immediate proximity of cities is an increasing practice in Europe.

The density factor makes the distinction between “doing things alone” or “together”

We do things “alone” when we drive in our own car and live in low density suburbs or detached houses in peri-urban or rural areas, whereas we are do things together when we live in compact villages, towns or the inner cores of large cities, when we share collective transport services (public transport or other forms, such as car sharing and/or pooling) or whenever we walk or cycle around a compact urban environment. “Togetherness” is seen here as the condition when people live in closer physical proximity to each other, and travel, work and enjoy leisure in compact city environments.

Combining the two factors above, the 2x2 grids helps us to identify four archetypal urban forms:

**First Quadrant**
Large urban areas, featured by suburban rings of low density around a monocentric city core. Following a typical urban sprawl dynamic, workplaces and consumption opportunities are mostly concentrated in the central city or – in a more recent tendency – in suburban production and consumption centres (e.g. office districts near international airports, large shopping malls in the periphery, etc.), whereas homes spread in rings of decreasing density around the periphery (the most frequent case for existing cities in Europe) or in extensive suburban areas with arrays of single houses (the most frequent case in the US). This pattern generates high volumes of car traffic, as it is difficult to provide alternative forms of transport at such low density levels. The concentration of workplaces and consumption opportunities in the city centre or in suburban centres causes congestion problems during daily or weekly rush hours.
Second Quadrant
A network of compact/high density city cores, connected by means of a fast transport infrastructure (e.g. high speed trains or highways) which allow people to travel comfortably between the cities during the day. Workplaces, consumption opportunities and residential districts are distributed within the urban cores, and high quality and fast public transport connecting different places can be provided thanks to the high density of transport demand within and between the cities. This helps to reduce the sort of congestion observed in the urban sprawl form, especially if individual car use in the urban cores is restricted. A variant of this form at regional scale is the realisation of satellite towns connected to one large urban core by means of fast and frequent public transport, i.e. creating so-called Transit Oriented Developments (TODs) around central cities, with mobility corridors to speed access to the centre.

Third Quadrant
Compact medium to small towns which include a full range of production and consumption opportunities for a population living mostly within the city boundaries. These cities are small and dense, relatively far from other cities and not connected by fast transport services which would allow return trips within the daytime, and host a variety of economic and social activities which make the city life vibrant and self-reliant. Workplaces and consumption opportunities are located within a short distance from people’s homes, and this – together with the relative high density – may facilitate walking, cycling and light public transport (bus services).

Fourth Quadrant
Sparse settlements of detached houses in the peri-urban areas and “diffuse city” patterns, the latter characterised by the spread of production, consumption and other urban functions over a large territory without a dominant urban centre. Consumption and production opportunities are usually located far from homes, but the distance and travel need can be mitigated by increasing the use of Internet broadband services. Low density in these areas do not allow for the provision of fast and frequent public transport services, and the incentive to build fast road connections is limited, which makes transport strongly car dependent and often affected by problems of road network bottlenecks and congestion.

Each of these urban forms is being studied now in the PACT project to analyse the transition to a post-carbon society, and how the dominant lifestyle, technologies and infrastructure for urban life, housing and mobility could/should change to drastically reduce the use of fossil fuels and CO₂ emissions. These changes may concern different ways of organising production and consumption activities, and different mixes of “fast” and “slow” activities which will characterise future urban daily activity profiles.

How the different urban forms may evolve in the post-carbon society

The city form most vulnerable to the end of the era of cheap oil is urban sprawl, the first quadrant, yet this is still the dominant one. Urban sprawl is the “business as usual” form of urban development, but may lead to collapse if uncontrolled sprawl continues when cheap fossil fuels become scarce. Serious oil shortages could lead to panic and even social collapse on a large scale. Even a slow decline in oil could unleash forces that are barely imaginable for car dependent suburbs, as those people who have little flexibility in their household income would increasingly have to spend a greater proportion of their money on transport fuel and for household power and fuel. Residents who moved to the suburbs in search of cheaper housing will be unable to adjust their budgets or lifestyles when faced with rocketing oil prices. And the option to switch to public transport or walking is often not feasible, just as alternative heating options are not available and vehicles cannot be fuelled.

The ruralised city form, with a diffuse city pattern (fourth quadrant), may offer a response to peak oil, provided that the sparse settlements are based on a more sustainable semi-rural lifestyle, and each city is responsible for producing a large proportion of its own food. This could be a kind of suburban agriculture based on hobby farms. In
this ruralised scenario most needs are met locally and the economy is devolved down to individual households or small groups. Heating is provided by wood grown locally and there is little need to travel as needs are met locally by a more self-sufficient economy. The rural evolution of suburbs has been well described by David Holmgren as follows: “Suburban sprawl in fact gives us an advantage. Detached houses are easy to retrofit, and the space around them allows for solar access and space for food production. A water supply is already in place, our pampered, unproductive ornamental gardens have fertile soils and ready access to nutrients, and we live in ideal areas with mild climates, access to the sea, the city and inland country”[67].

However, there are two problems with this approach. First, it provides a new rationale for urban sprawl, which will consume land and other natural resources. Second, it distracts us from seeking region-wide solutions to energy, water, waste and food production issues in favour of individualised approaches, which may be not equitable. Cities are collective entities and should solve their problems through common good solutions to avoid the risk of becoming highly exclusive.

There already exists a whole array of eco-village experiments which can serve as models for how rural areas can be productive and sustainable (see for instance the Global Eco-Village Network[68]), and they are now moving into cities to create intentional communities – “urban eco-villages” – in which the residents share social, environmental and economic goals. There is also a tradition of agriculture within cities, and the potential for urban agriculture to provide a substantial proportion of the city’s food needs, most notably in the Third World. Food production may become available to residents of ruralised cities through means such as roof gardens, allotments, community gardens, backyards and eco-villages designed specifically for urban areas[69].

However, urban agricultural production should not be the primary function of the city. There are other rural functions that could be brought more directly into the city fabric of the future. Cities will need to be more closely connected to the creation of renewable energy, the provision of water, and the processing of waste. These functions are moving into smaller-scale technologies that can fit more easily into cities and will be much more energy efficient, but they need to be built into the city fabric as a public service, to ensure an equitable society. While there exists an emerging movement to reuse vacant lots for growing food, there are limited opportunities for this in the densely populated parts of cities. On the other hand, these centres are where traditional urban functions are concentrated and where public transport and walking are feasible due to the density. This conflict between the need for density and for green open space is a real issue for urban sustainability.

In conclusion, the ruralised city model can be considered a viable option for the future post-carbon society in particular circumstances, i.e. for peri-urban areas which due to oil shortage will be no longer viable as car-dependent suburbs, and can be phased into being more rural. In this situation, it is possible to imagine that urban eco-villages could colonise the space. In these places, much of a city’s renewable energy could be produced; waste could be mined, treated and recycled using advanced technologies; and some of the city’s specialised food needs could be produced.

The compact city form (third quadrant) was the traditional urban form in medieval Europe. Today it is the form used for new “gated communities”, mostly in the US but also in some areas of Europe. These are forms of divided cities where the wealthy recognise that they need to optimize their choices and begin to form exclusive neighbourhoods and self-sufficient centres with the best public transport and a pedestrian-friendly environment. The


[68] www.gen.ecovillage.org

residents of these compact centres live in walkable, mixed-use urban communities with access to jobs and amenities. All necessary services are within a short distance and all institutions for supporting such centres are available locally. Likewise, the best solar design and renewable technology can be built into these compact areas. In the post-carbon society, compact small towns – either new towns built up following the New Urbanist agenda that calls for pedestrian-friendly, higher density and mixed-use communities, or historic towns in many areas of Europe – may function as “eco-enclaves”, where residents have reduced travel needs and use energy produced mostly by renewable sources more efficiently.

But this model is not a solution for all, as the social and demographic balance of small towns is vulnerable to any large inflow of new population, which could not be welcomed to the city due to the restricted employment and investment opportunities. The limit of this urban model, then, is that it is relatively closed and isolated, and may easily evolve into a divided city, where poor populations are simply excluded outside the city boundaries.

Finally, in the network city form (second quadrant), the access and alternate forms of transport and land use in eco-enclaves that are the province of the residents in the compact small towns are provided for all. Envisioning how this city model will work in the post-carbon society, people will have access to jobs and services by transit or walking as well as by using electric cars for short car journeys. Intercity movements will move toward fast electric rail and be reduced considerably by a new generation of high-quality interactive video-conferencing. Green building design and renewable fuels will be a part of all neighbourhoods. The city will develop new rail links to all parts of the city, pedestrian-friendly centres will be created across the city-region using the best green buildings and infrastructure. In areas between the intensively developed urban cores and corridors, urban eco-villages will be established to help manage the city’s ecological functions such as extra renewable energy production, and water and waste recycling; these will be linked into a city-wide green infrastructure system through clever control systems (smart grids) and local management. Urban eco-villages will also grow specialised agricultural produce and manage areas of urban biodiversity; they will be largely self-sufficient although they will still be within easy reach of the city for many urban functions.

In the rural regions around cities most agricultural and forestry production will focus on food and fibre and biofuels for the city and its region, thus reducing food and fibre miles. Manufacturing will become more localised and be more biologically based, to replace petrochemicals. Towns where goods are produced will be linked mainly by freight rail to the city. All these changes will be supported by the extension and use of intelligent systems to ensure the timing and flexibility of goods and services provision, and the exchange of real-time information flows and knowledge.

Of course, the changes towards a post-carbon society envisioned above are not simple, and there is no question that the transition will be difficult and will follow uncertain pathways. The PACT project will continue to analyse in more detail the technological, infrastructure, industrial, behavioural, social and policy changes needed for a complete reorientation of society and a new organisation of urban life [70]. However, as a first, provisional conclusion of analysis undertaken so far in the project, it has been highlighted that we are now at the start of a new era of resource productivity and investment in a new wave of sustainability technologies related to renewable energy and distributed, small-scale water, energy and waste systems, building on clever control systems and smart grids, all of which are more local and require far less fuel to distribute. This all means that the city could become much more polycentric, tending towards the city network model described in the second quadrant above. The transport systems that support such polycentric urban forms appear to be new electric transit systems for fast cross-city movement and

[70] See also European Commission (2010), World and sustainable cities – Insights from EU Research.
a series of small-scale electric and hybrid vehicles for small local trips as well as walking and cycling, which have survived all the city form changes. The polycentric cores and the remaining suburban buildings need to be renewed with solar and other eco-technologies. It is clear that these changes are not just technological substitutions, they entail shifts in business paradigms, in the culture of utilities that will provide the infrastructure, and in the organisation to enable new ways of managing our cities.

2.2.2 Renewable energy and the competition for land

Harvesting renewable energy: land-use issues

Today’s main renewable energy technologies aim at harvesting solar, wind and biomass resources. This chapter will concentrate on these current promising technologies for a transition towards post-carbon societies over the next 30 to 50 years. More prospective technologies currently undergoing initial development could additionally help collect tidal and wave energies, or cultivate and transform algae for energy purposes. In the very long term, oceans could be large energy suppliers and perhaps cover much of our needs. There are also plans for long-term energy supply through highly concentrated energy sources like nuclear fourth generation or nuclear fusion.

Energy technologies can be defined both by the nature of the energy source that supplies them and by their generation scale [see figure below]. Energy sources are concentrated or diffused, while generation capacities are centralised or distributed. Renewable energies are almost always diffused energy sources. As defined in the matrix below, energy technologies can be implemented in urban or rural areas depending on their category. Solar photovoltaic technology, for example, as a diffused energy source, can be used either as a centralised power plant in a rural area or as distributed generation on residential buildings. There are already over 1000 large-scale – above 1.3 MWp – PV projects in the world and almost 100 very large scale

PV power plants – above 10 MWp(71) – mainly in Spain (70% of solar capacity in 2008) and Germany (13%). But over a quarter of total installed PV capacity in the world in 2008 was for on-site electricity generation, and the distributed PV market share is over 98% for almost all countries except Germany and Spain.

One common feature of diffused energy sources is that their capacity is proportional to the land surface they cover. Large-scale production requires a large area, which explains why high density areas [ie. urban centres] are not suitable for collecting significant amounts of renewable energy.

Energy technologies across the nature of energy sources and generation means

Types of collection areas across the nature of energy sources and generation means

[71] World’s largest photovoltaic power plants [ranking 1-50], http://www.epia.org/
A matter of balance between urban and rural areas

Today, the energy balance between rural and urban areas does not favour rural areas. Energy demand in rural areas is moderate due to the small population, yet these zones supply almost all energy to the system, mainly through centralised conventional technologies. Urban areas in contrast, consume a lot of energy. The current situation thus requires huge energy transfer between the two land-types, with a total energy consumption globally that is too high to be compatible with a post-carbon world.

In a business-as-usual scenario, the energy transfer between rural and urban areas would only increase, due to greater energy demand, making the energy system still more unbalanced than it is today. This would be the case even if renewable energy was implemented at a larger scale than it is today in both areas.

In a post-carbon scenario, the energy system would be more balanced between urban and rural areas. Both areas would increase their post-carbon compatible renewable energy collection, while the former energy supply from rural areas (i.e. centralised CO₂-emitting technologies) would dramatically decrease. Simultaneously, total energy demand would decrease thanks to high levels of energy conservation and energy efficiency. Finally, energy would mostly be produced in-situ, with networks ensuring the remaining necessary transfer between areas.

A matter of balance between high and low density urban areas

Urban areas will probably continue to have an adverse energy balance, whether in areas of high or low population density. This is because of relative land scarcity and high land value, which prevents the installation of energy production capacities on this sort of territory, especially as power generation in rural areas has been profitable due to low energy transmission costs (high land availability at low cost). Other factors that have contributed to the deficit of energy production in urban areas include the risks and social acceptability associated with concentrated power generation in populated zones. Indeed, only a small portion of energy consumed in urban areas today is produced locally, and this is mostly in low density urban areas. There is almost no in-situ energy production in high density urban areas.

Reducing the energy deficit of urban areas would require increasing on-site energy production and cutting energy consumption. The means to
achieve these results could be very different for high and low density urban areas, however: large quantities of renewable energy are difficult to produce in compact urban areas, while large-scale energy-efficiency programmes for buildings and public transport are very feasible. On the contrary, energy consumption in the least dense urban areas would remain higher because of the unavoidable need for individual transport. However, the availability of larger sites would allow more renewable energy to be collected in these areas.

Ultimately, the demand for residual energy supply for urban areas, especially populated ones, could be met through networks of energy (renewable heating and/or electricity) produced in less dense urban or rural areas.

As a conclusion, a post-carbon scenario would have to minimise, as far as possible, energy supplied from centralised technologies that are incompatible with a zero-carbon energy system. One way to manage the transition towards this objective is to re-balance rural and urban energy systems and reduce the energy dependence of urban areas, as illustrated above. However, current trends run largely counter to this desirable future, so specific policies and measures would be required to reach the target.

From an economic point of view, in order to reach post-carbon targets for the lowest possible implementation cost, and be profitable in comparison with the business-as-usual case, policies would need to provide mandatory rules and incentives to counteract some land-value effects and to compensate for the high cost of developing new energy technologies. The right energy technology should then to be used at the best place according to land-type and available energy resources.

Collecting energy in urban areas

There exist two possible models for urban areas in a post-carbon society which aims to reduce the energy dependency of rural zones and re-balance energy patterns:

Dense areas, which have a large potential both for energy efficiency and to reorganise their networks, but low renewable energy supply potential because of space constraints. In contrast, sparse urban areas will maintain a greater energy demand due mainly to an unavoidable need for mobility, but have greater opportunities to harness diffused renewable energies.

Compact urban areas

With a growing world population, human settlements are expected to become increasingly dense in cities over the coming decades, including at the European level. In compact urban areas, renewable energy can mostly be collected from available roofing areas, using solar panels (thermal collectors or photovoltaic panels). But building configuration in these zones is often
Exploiting renewable energy may require a complete land conversion from the primary land-use. But there should be some complementarity between energy production and other land-uses in non-urban areas. Solar power density is greater than wind energy density, but solar power plants cover 100% of the land and prevent multi-use, unlike wind turbines. This is why every situation requires a detailed evaluation of the costs and benefits from all land-uses.

Renewable technologies are suited for various land-types, and it helps to define the best-suited technological option for a given land-type, and second possible option depending on a number of factors. For instance, solar technologies are well suited for built-up areas and marginal sunny lands like deserts. But they are not the best option for agricultural or grassland areas. Wind energy is well suited to agricultural and grassland areas because it allows for multi-purpose land-use. It is also possible in built-up areas, but is not suitable in forests or mountainous zones. Biomass production is possible in existing forests and on grasslands as these also offer the least competition with other uses. Although it is still possible to produce bio-energy on farmland, this will be in stiff competition with the production of crops and livestock products.

### Table 2.5: Renewable energy sources and land-types

<table>
<thead>
<tr>
<th>Land-type</th>
<th>Solar</th>
<th>Wind</th>
<th>Biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Built-up areas</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Agricultural land</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Grasslands</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Forests</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Marginal land</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

1 indicates first best options  
2 indicates second best options to collect diffused renewable energy of the given land-type
The opportunity for better land management

Harvesting renewable energies in non-urban areas can offer the opportunity for land requalification and better management. It may also allow for the re-shaping of landscapes, restoring some of their natural features, by investing massively in under-populated regions. Interest in these areas has decreased over time, but renewable and land-intensive energies could allow for a certain level of activity to be maintained in low density regions of developed countries, which are finding it hard to compete with emerging countries for food production.

In Europe for instance, wind energy could be the opportunity to restore value to the countryside following a decline in farming activities, adding new value to neglected lands. Energy crops would offer farmers an opportunity to diversify their activities towards new products.

Collecting renewable energy could also present an opportunity to add value to certain marginal lands, making them attractive and profitable. Solar energy is one of the most promising renewable energies for deserts or other barren regions. Bio-energy production could be possible on marginal lands that are not suitable for agriculture. This could also relieve pressure on densely populated urban areas in environmentally challenged regions, by limiting rural migrations, in particular in some developing countries. Using degraded or marginal land could thus allow renewable energy to be produced at the lowest environmental cost, and bring efficient and modern infrastructure to far-flung regions.

Competition for land-use and associated risks

Identifying future constraints

Wind energy and solar on-site energy production will not face many other constraints than economic and societal ones. Their future deployment will depend mainly on their technical/economic potential as assessed in the next section.

On the contrary, centralised solar power (CSP or PV) and especially bio-energy production will face major constraints to their development related to the question of land-use. For a start, they are suited to the same sort of land-type, which is usually devoted to other uses: social (entertainment, landscapes), economic (infrastructure development, material production) and environmental (biodiversity, set-aside).

With a growing population, competition for land-use will become crucial, and demographic changes will probably require more land conversion to satisfy growing food needs. The likely benefits of producing renewable energy in rural areas should not mask the potential constraints and risks.

Renewable energy production’s most serious competitor for land is cropping and stock farming. Most land-use today is dedicated to agriculture: 38% of the total surface worldwide, 32% of which is used for arable land and permanent crops, the remaining 68% being permanent pasture and meadows (73). The share of agricultural land in the European Union is higher but decreasing. Currently, it accounts for 45% of total land area, compared to around 53% in 1970. France and Spain account for 15% each of the total European agricultural area, followed by Germany and the United Kingdom (9% each) and then Poland (8%), Italy and Romania (7% each).

The total agricultural area will probably expand at a global level to satisfy food and energy needs, although this expansion will depend on the evolution of yields, which in turn depend on climate and soil quality. There is also potential unused arable land in Europe: actual arable land is estimated to be 50% (74). Moreover, 21% of soils have no major constraints although there are great disparities between countries: 54% of soils in France are without constraint, but only 3% in Spain (75).

In the future, a greater proportion of land may be devoted to renewable energy production in an effort to combat climate change. In this context,

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one challenge will be how to meet the various [growing] needs in a sustainable way. The large-scale use of land for energy purposes is already controversial, as there are fears it will compete with farming to the detriment of the environment. Other land-types will also be investigated for the production of renewable energy, including unused arable lands, natural grasslands [including shrublands] and marginal lands.[76].

**Risks for sustainability**

Three main risks are clearly identified:

**Risks for biodiversity**

European forests are expanding nowadays, and suffer from a lack of overall management and maintenance. But their intensive exploitation, triggered by a high value being attributed to forestry products, may provoke unsustainable outcomes. For example, first generation biofuels have been associated with deforestation (palm oil production in Indonesia and sugarcane in Brazil), as well as damage to biodiversity.

For non-cellulosic crops – oil and sugar crops used in the production of first generation biofuels – the main issue consists in finding the largest quantity of these crops that can be produced without harming the environment and without affecting food supplies. Used to produce ethanol or refined oil for transport, they include sugar-cane, sugarbeet, oil seeds and sunflowers. They have huge impacts on the environment and in some cases produce many by-products (which can be used for other energy purposes).

Short rotation crops used for bio-energy production would probably include clones or GMOs, with the associated potential risks for biodiversity. Intensification of farming activities is also a great threat to biodiversity.

**Risks for water resources**

Water scarcity and the depletion of water resources (as in southern Europe) or the pollution of underground water (Brittany in France) is a great threat to sustainability. It would thus be necessary to study the potential impact of developing bio-energy on future water resources.[77].

**Risks for soils degradation**

Extensive land-use for energy purposes may accelerate the degradation of soils, in particular through intensive farming. The degradation of land due to farming is a widespread problem: according to the FAO, 38% of the European Union is degraded, 36% of which due to agricultural activities [compared, respectively, to 26% and 35% at the world level][78]. The intensification of farming to the detriment of more traditional, environmentally friendly agriculture has accelerated the degradation of natural areas and overexploitation of soils (for example in Eastern Europe).

The Common Agricultural Policy reflects the multiple objectives of farming in the EU: "While the primary role of farming continues to be food production, farming and rural land management also perform a complex set of functions for society, including the provision of a range of environmental benefits and the maintenance of rural social fabric, especially in more marginal areas. The multiple objectives of the CAP reflect these varied functions of European farming".[79].

**Risks for markets and food supply**

The large scale use of biomass for energy purposes is controversial, as the recent food crisis highlighted. Various explanations have been made for the recent increase in food prices: competition for cropland from the growth in biofuels, low cereal stocks, high oil prices, speculation in food markets and extreme weather events. According to Cooke and Robles, the fluctuations are not directly due to economic fundamentals of demand and supply on food markets, but were caused by financial activities
and/or speculation. It nevertheless sent a clear signal to the global economy of the risk of potential unrest in the food market.[80]

It also underlined the need to study the global food market, assessing future supply and demand.[81]. The average diet will play a central role in the evolution of global food requirements, while the evolution of yields will determine the capacity of countries to meet their national demand. It is still not clear today what trade and dependencies between regions will be necessary in the future, or the likely stress on food supplies (in relation to water availability and land devoted to agriculture).

According to Dornburg[82], biomass for energy purposes cannot be decoupled from food production, because they both require land, and available land is finite. However, there is a potential to weaken the link between food and bio-energy, through technological development, intensification of farming, agricultural reorganisation and the use of new biomass sources.

First generation biofuels exposed the direct competition between energy and food products, because they are based on “food” crops like corn, rapeseed, sunflowers and palm oil. There were clear correlations between food prices and the development of biofuel production in some countries (the US and Mexico). While second generation biofuels will also compete with the food supply, they will do so at a different level.

Some efforts have been made in models to tackle the food-energy nexus, and its possible impact on future land prices.[83]. But generally speaking, interactions between energy and food supply should be carefully analyzed. The European food security policy (CAP) has to be considered, taking into account the potential risks for the long-term stability of food markets at both a European and global level.

Accounting for land-use restriction in the evaluation of the potential of renewables

Assessing renewable energy potential

The potential of renewable energy sources must be carefully evaluated for each type of land, both in terms of quantities and geographical coverage. In a sustainable economic perspective, the potential would affect the future profitability of investments and their environmental sustainability. Once the potential is identified, technological roadmaps can provide useful indications to exploit them efficiently and avoid future market bubbles due to over-investment. The PACT project aims to indicate the best pathways toward post-carbon societies, including for the development of renewable energies.

As data on renewable energy potential needs to be put into context, it is important to define the type of potential that is considered. Five categories, represented as a nested structure, are commonly used to assess their future potential:[84]:

- the theoretical potential is the theoretically upper limit of available energy supply, determined by physical constraints;
- the geographical potential is a restriction of the theoretical potential to the suitable geographical locations;
- the technical potential is the share of the geographical potential that is technically feasible, taking into account the conversion process efficiency to secondary carriers. The technical potential changes over time as the technologies change;
- the economical potential is the technical potential that can be realized at a profit, depicted by a cost-supply curve with a maximum at the technical level;

[82] Dornburg, V. et al. (2008), Global biomass potentials and their links to food, water, biodiversity, energy demand and economy, Netherlands Environmental Assessment Agency, Bilthoven.
the implemented potential is the actual amount of energy implemented within a given time-frame, taking institutional constraints and incentives into account.

The amount of solar energy received by the Earth’s surface each year would be thousands of times greater than our global energy needs. Diffused solar energy can be captured either directly or naturally transformed under the kinetic form (wind), potential form (hydro) or chemical form (biomass). For each of these forms, the theoretical potential is huge and represents several times our annual energy needs. As a consequence, the available renewable energy is usually not the bottleneck for the diffusion of renewable technologies. The difficulty is rather in collecting diffused energy in a profitable and sustainable manner. This is why we define the geographical, technical, economical and implemented potentials.

Most restrictions to the available potential arise from land-use constraints. There may be competition with other land-uses, for example, or social acceptability issues, resource quality issues or environmental impacts. Most studies into the potential of renewables begin with an evaluation of the theoretical potential to which exclusion factors, standing for various constraints, are progressively applied. The potential of solar, wind, biomass and hydro energy are reviewed in the following sections and summarised at the end.

Many studies and scientific articles have been published assessing one or more renewable energy potentials. Johansson [85] provided a first integrated assessment for all renewable energy sources, quickly followed by many other efforts [86]. The results are varied and largely depend on methodology, data source and assumptions. We try here, as far as possible in a short chapter, to summarise the main results.

Land-use constraints and solar energy potential in the EU

Building integrated solar potential
The International Energy Agency suggests that in developed countries by 2050, almost 40% of the building stock will have been built after 2003, which provides a huge technical potential for solar integration in new buildings [87].

Two categories of buildings defined by the IEA would fit with our two types of urban areas: Single-Family Detached buildings in low-density urban areas and Multi-Unit Attached buildings in high-density urban areas [88]. The distribution of sparse and compact new housing is equal in most European countries.

Figure 2.59: Sparse vs Compact Housing new constructions in some European countries in 2003


[88] The IEA also defines an intermediate building type called Attached Housing which is an in-between of the two other categories. This category would better fit with our sparse urban area definition and would correspond to a second ring suburb housing type [ie. sparse urban areas]. Furthermore, this category is quite irrelevant in terms of potential as forecasted constructions are far less than for the 2 other categories.
Centralised solar power potential

Concentrated Solar Power (CSP) technology can be implemented only in very sunny zones, usually over 2,000 kWh/m²/year on average. This technological constraint restricts the technical potential almost exclusively to deserts (far south of Europe) which have the advantage of being sparsely populated but the drawback of being distant from centres of consumption.

On the contrary, large photovoltaic power-plants [over 1 MWp] can be installed in less sunny regions and 1,000 kWh/m²/year can be considered as enough, judging from the experience of Germany in this field. However, while such areas could include temperate populated areas in Europe, competition for land would prevent such large plants being installed unless there were huge incentives. Large photovoltaic power-plant potential is also reasonable in very sunny areas like deserts. The potential assessment of CSP and large PV would thus be calculated in the same manner, as they are similarly land-intensive technologies and because their land-type requirements overlap.

DLR [2008] evaluates the total solar technical potential at 3,000,000 TWh/year, or 160 times the global electricity consumption [91]. But this potential is rather scarce in Europe, except in the very south of the continent. Spain is the European country with by far the largest potential (1,278 TWh/year). Indeed, the region of Andalusia has recently seen the commissioning of the first European plants, PS10 and PS20. Portugal (142 TWh/year) and Italy (7 TWh/year, mainly in Sicily) also offer some potential [92], while Cyprus and Malta would be able to produce centralised solar power [with respectively 20 and 2 TWh/year potential].

Anually, the new buildings potential represents around 0.5% of the total PV potential of existing stock [0.4% to 0.7%, depending on the country]. By 2050, the integrated potential in new construction would thus reach around 20% of the total potential of today’s existing stock.

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[92] First restriction excludes 40% of roofs area and second restriction excludes 45% of roofs area according to IEA assumptions.
[94] See the DLR MED-CSP study available at http://www.dlr.de/tt/desktopdefault.aspx/tabid-2885/4422_read-6575/ Data on potentials are reported for areas with solar irradiation over 2000 kWh/m²/year, called economic potentials in the DLR study.
Land-use constraints and wind energy potential in the EU

Wind atlases are very useful for assessing the meteorological potential of both on-shore and off-shore wind. The meteorological potential represents the available area, expressed in km², where the mean wind over time exceeds a certain value at a height of 10 metres. The atlases are produced using wind resource models like WAAAP, Wind Atlas Analysis and Application Program, which computes the annual mean wind speed for thousands of grid points. The results are then fed into Geographical Information Systems (GIS). Wind atlases and meteorological potentials have been well documented for some time, both for onshore [93] and offshore wind energy [94].

The site potential is obtained by applying exclusion factors due to land-use and social constraints to the meteorological potential. It is also expressed in km² and represents the restricted portion of the meteorological potential available for wind energy generation. For instance, marine protected areas should be excluded from the calculation of the offshore potential. Finally, the characteristics of wind turbines and wind fields provide the technical potential that is the maximum wind electricity it is possible to produce in the potential site.

Recently, the European Environment Agency has used the ECMWF’s ERA-40 reanalysis data set [95], which describes the climate over 40 years, as a primary source for its meteorological potential assessment [96]. The onshore potential is usually divided into wind classes, based on average wind speed at 10m above ground level. Class 3 represents winds with a lower energy content (over 5 m/s) but still potentially suitable for power production; class 4 is the intermediate class (almost 6 m/s) and classes 5-7 contain the most powerful winds (over 6 m/s). The study takes into account the interaction between wind flows and the surface (roughness and relief), using the agency’s Corine Land-Cover database. Offshore meteorological potential is assessed for countries Exclusive Economic Zones, excluding water depths over 50m. Offshore wind classes are usually defined by distance to the coast.

[95] ERA-40, http://www.ecmwf.int/research/era/do/get/era-40
Technical aspects are crucial to identify the technical potential because incident wind power depends on the hub height of the machines[^77], and average turbine spacing depends on their capacity size[^98]. First, then, we need to make assumptions about the future nominal power of wind turbines. According to the EEA, onshore wind machines are expected to soon reach an average ceiling of 2 MW per unit (from 1.5 MW today), while offshore turbines should continue their growth up to 8 MW on average in 2020 and 10 MW in 2030. There is a clear correlation between the following three variables: the wind machines’ nominal power, their diameter and the hub height. Hub height and rotor diameter should stabilize on average at 80m for onshore wind machines while they would reach 120m and 140m for offshore wind machines respectively by 2020 and 2030. The capacity of wind machines is also supposed to evolve according to technical progress over time.

Northern Europe, as the windiest and flattest region, is most suitable for onshore wind power. European countries with the largest technical onshore potential (excluding forests, mountainous and built-up areas) are France (around 3000 TWh/year) and the United Kingdom (around 2500 TWh/year), followed by Poland and Germany (around 2000 TWh/year). When protected areas are excluded from the calculation, Europe’s technical potential falls by almost 15% (according to a social constraint evaluation from the cases of Germany and Denmark).

The largest offshore wind energy potential in Europe is around the North and Baltic Seas. Countries with the largest potential are the United Kingdom (around 3000 TWh/year), followed by Denmark and France (between 1500 and 2000 TWh/year) and Finland and Norway (between 1000 and 1500 TWh/year). Restrictions to offshore technical wind potential may include shipping routes, military use, oil and gas exploration and tourist zones, and even part of the near-shore potential due to visual impact. The restricted offshore potential could fall by 88% to 3,500 TWh/year for Europe in 2030.

[^77]: Wind-speeds at hub height are usually extrapolated according to a power law according to equation: $v_x = v_0 \times (h_x / h_0)^\alpha$, where $v_x$ and $v_0$ are wind-speeds $h_x$ and $h_0$ are hub heights. Grubb and Meyer (1993) show that a value of 1/7 (≈ 0.143) for alpha is often appropriate for very smooth sites (adapted for offshore potential calculation). For onshore potentials, a value for alpha supposed to be appropriate for inland sites is close to 0.16.

[^98]: Wind flows may be disturbed by the wind machines themselves, and machines cannot all work at their best in a wind farm. The array efficiency gives an indication of the losses due to the interferences between the various turbines. It depends on spacing between turbines and other parameters like the nature of the wind regime or the flatness of the site.
Many studies have shown, like the EEA that the technical potential based on exclusion factors due to geographical or social constraints still far exceeds what could be expected from wind energy generation in forward-looking scenarios.

However, one of the main constraints to the development of wind technology is linked to its integration into existing grids. This is so important that costs should be added to variable production costs in order to make up for the excessive costs of system management and back-up capacity maintenance. These depend on the penetration rate of intermittent technologies and the regional dispersion of production capacities.

Actually, very few studies take the constraints of grid-integration into account in their assessment, although it has been proved to be as important as social acceptability. The literature assumes generally that a 25% penetration rate of wind power could be a maximum, but situations may vary between countries, depending on their interconnection with neighbours.

Land use constraints and bio-energy potential in the EU

Traditionally, biomass was used in the region in which it was produced. However, this pattern has lately changed in northern Europe and North America. Solid biomass like wood residues and biofuels are now traded and there is a growing interest in international trade in other countries. However biomass with low heating values is still limited to local uses.

The economic status of biomass can be “traditional” (i.e. not commercial biomass) or “modern” (i.e. commercial biomass). Traditional biomass is not driven by market prices, but follows trends linked to the level of development and the proximity of the biomass resource. The exact amount of traditional biomass today is not known, especially in developing countries. Furthermore, with economic development, traditional biomass will tend to disappear, to be replaced by commercial biomass.

The two main biomass types, residues and energy crops, are quite well defined in the literature. They represent more than 85% of the total biomass availability, but their estimated potential is still controversial and mainly depends on sustainability factors. The largest biomass resource is in cellulose form.

Residues come from both forestry and agricultural activities, and include wastes (animal, municipal and industrial). They are usually thought to have a rather limited potential, and their availability is not exempt from questions of sustainability.

Energy crops can be both non-cellulosic (oil and sugar crops for first-generation biofuels) and cellulose (short-rotation crops – SRC). While the first category competes directly with the food supply, the second presents no direct competition. SRC consist of fast-growing plants such as poplar or eucalyptus, depending on the region, to produce wood pellets for uses ranging from power generation to the production of second-generation biofuels. Several land types may be used to produce SRC (marginal lands, pasture, woodland, shrubland), although they can also be grown on farmland and thus indirectly compete with the food system. Environmentalists have warned of the potential threat to biodiversity of such plantations, as most of the future bio-energy potential is supposed to come from this resource. Energy crops are thus at the heart of the controversy surrounding food security and biodiversity.

In developed countries, the amount of available biomass, as well as its cost, is intimately dependent on agricultural policies. The issue of competition with other biomass applications makes difficult to draw any firm conclusions about the amount of biomass that will be available for energy purposes. An expanding biomass sector would interact with other land-uses, with impacts for food production, biodiversity, soil and nature conservation, and carbon sequestration. The projected food and material demand together with land-use efficiency in agriculture and forestry will determine land requirements for food and materials production. It will thus also determine the availability of land for biomass for energy production (but also biodiversity, recreation...). Figure 2-62 reviews the flows between biomass categories and describes the competition between biomass for energy, and biomass for food and materials.

The black arrows indicate the main product flows, whereas the dotted lines show potential non-energy applications of various residue categories. The grey arrows represent the potential energetic use of the resources [1 = energy crops, 2 = food/feed crops, 3 = material production, 4 = forest harvest, 5 = material production, 6 = food consumption].

Figure 2.62: Overview of biomass flows and the global land surface


2 = energy crops from degraded land, 3 = agricultural residues, 4 = forest residues, 5 = animal manure, 6 = organic waste, 7 = bio-material).

Studies into the future potential of biomass cover a wide range of results, which may vary by an order of magnitude due to a wide set of assumptions. The differences and uncertainty are huge also because of rough input data-sets and approximate definitions of biomass categories and potential types. The total biomass potential for energy supply in Europe ranges from 3 to 13 EJ/year\(^{(103)}\), while the global potential ranges from 50 to around 700 EJ/year\(^{(103)}\). There exist several papers focused on Europe\(^{(106)}\) and also many global studies with synthetic assumptions\(^{(109)}\). The main parameters are demography and the evolution in the average diet which define the interactions with the food system (and thus the remaining land area available for other land-uses like bio-energy production), and the rates of productivity increase of various land-types.

An investigation into the resource potential of biomass can be handled through scenarios that incorporate an examination of the impact for ecosystem sustainability (biodiversity), agricultural management (fertilisers and exploited land surface) and impacts on food supply (i.e. food prices). In other words, scenarios concerning the potential of biomass should be accompanied with environmental, economic and social considerations. The land-use change and associated environmental impacts may be detailed for each scenario. For instance, deforestation is a threat that should also be evaluated in terms of GHG emissions. Van Vuuren\(^{(106)}\) explored the impact of various parameters for the total biomass available for energy purposes (accessibility factors for forests and natural grassland, exclusion of land with potential for severe soil degradation, water scarcity or high biodiversity value), and elaborated storylines around visions for 100 EJ/year, 200 EJ/year or 400 EJ/year long-term bio-energy potentials.

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\(^{(104)}\) How much bioenergy can Europe produce without harming the environment?, EEA Report No. 7/2006.


2.3 | Chapter 3

The social fabric of the energy and environment transition

2.3.1 | Enablers and obstacles: insights from anticipatory experiences

The developments below are based on the results of research carried out by LSC (Laboratorio di Scienze della Cittadinanza, Roma) in the first phase of the PACT project (107).

Anticipatory experiences to understand transition mechanisms

As part of the PACT project, we identified a series of “anticipatory experiences” of energy transition. Because of their peculiar characteristics compared to other eco-sustainable energy initiatives, we were able to infer from the anticipatory experiences the main features that characterise or may characterise energy transition as a whole.

The concept of “anticipatory experience” refers to the theories of “anticipatory systems”, developed in particular by Rosen (1985, 1991) in the sphere of biology and developed, in the social context, especially by Nadin (1998, 2003). These theories, based on scientific evidence, maintain that living systems (from individual organisms to collective organisations) contain, albeit in different forms, biological and social mechanisms that can “anticipate” changes that actually occur (either in the micro-environment or in wider and more complex areas of social life).

The presence of these “anticipatory systems” allows for the organisation of actions not only in reactive terms (reacting, that is, to a situation that involves them) but also in “predictive” terms (anticipating, that is, the same situation and adopting an internal organisation or plan of action before this situation occurs, modifying it in advance, at least in part).

For our purposes, anticipatory experiences are to be viewed as cases where the participants, interacting with each other, anticipate situations and processes which may be typical of energy transition as a whole.

About 270 eco-sustainable energy initiatives defined as “emerging experiences” were identified, through:

- expert advice;
- sending a “call for experiences” (with attached form) to 800 addresses selected from the PACT (WP7) mailing list;
- a web-based survey of case-study databases (Concerto, ManagEnergy, Energie-Cité, CIVITAS, etc.).

Each of the 270 initiatives was screened on the basis of information collected and filed according to descriptive parameters (type of project, scope of action, size, number of people involved, etc.). Then, using four theoretical and methodological criteria (factualness, social impact, transparency, systematicity), a first group of 60 “anticipatory experiences” was identified and then the smaller group of 20 experiences was selected for further analysis of transition mechanisms, within two theoretical frameworks.

The first relates to the actors involved in energy transition, who were grouped into three energy transition regimes:

- the energy production and distribution regime (REGIME 1), which includes actors such as companies, institutions and public bodies responsible for regulating the energy sector;
- the individual consumption regime (REGIME 2), where the main actors are private individuals or associations;
- the collective consumption regime (REGIME 3), involving actors such as companies, small and medium enterprises, public service institutions (schools, hospitals, etc.) and anyone who may be considered “major energy consumers”.

The second theoretical framework centres around three sociological categories, used to analyse the three energy transition regimes:

- the “structure”, which refers to everything affecting the action of the actors, both of a physical nature (e.g. networks and infrastructure), and of purely social nature (standards, rules, behavioural models, organisational procedures, routines, power configurations, dominant cognitive models and representations, etc.);
- the “agency”, which refers to the actors’ aptitude for action, expressed, for example, in widespread intentionality, forms of social mobilisation or the design of projects or negotiations oriented towards the achievement of specific goals;
- the “social capital”, which refers to the level of social integration, expressed in aspects such as the degree of mutual trust among citizens and between citizens and public authorities, and the cognitive capital, i.e. the information, knowledge and skills contributed by local actors and the institutions in charge of developing them.

These sociological categories, applied to the analysis of the regimes, allowed us to identify empirically some 700 de facto situations, among the 20 experiences, both in “operational” terms (i.e. events, happenings or other materials and immediately visible elements), and in “cognitive” terms (i.e. cultural orientations, behavioural models, representations of reality, symbolic materials, etc.).

These 700 de facto situations were compared to each other so as to “condense” them into more general categories, using linguistic processes (e.g. bundling together situations that were similar, even if recorded in different linguistic forms) or elementary abstraction procedures (for example, by including situations in the same category which differed only in terms of technologies used or contingent elements typical of individual experiences).

Thus these situations were condensed into about 249 recurrent “phenomena” in anticipatory energy transition experiences. As such, they can presumably be regarded as characteristic of energy transition as a whole.

The recurrent phenomena were analysed using both standard logic (to identify possible cause-effect relationships), and – almost necessarily – non-standard deontic logic (to assess the intentionality of the different actors involved in energy transition). In this way, it became possible to establish links among phenomena (based on, for example, their features, the meaning given them by the consulted sources or their recurrent mutual relationships) creating clusters of phenomena referring to broader categories.

This led to the identification of 43 factors that could be said to constitute energy transition, of which the 249 recurrent phenomena are indicative.

The constitutive factors can be defined as social configurations that have force and directionality, produce a meaning, are linked to more general trends of social and cultural change, and are constitutive of energy transition.

- The factors are social configurations, since they each involve, in a typical way, energy transition actors and therefore affect one or more transition regimes.
- The factors have a social force able to produce effects related to energy transition.
- The factors have directionality, since they show an intrinsic orientation towards energy transition, which can either take the form of obstacles to overcome (and therefore the expression of existing resistance or elements of local social structure that oppose energy transition) or enablers (i.e., elements that facilitate energy transition, activating agency mechanisms) present locally or which, if absent, are being encouraged.
- The factors produce a meaning in that they define relatively stable and recognisable contexts of meaning (such as knowledge, narratives, intentionality, representation, stereotypes, etc.) which are the object of communication, exchange, collection and processing by the actors involved. These contexts of meaning concern aspects of energy transition (e.g., technology, decision making, planning, participation, transparency, common behaviour, etc.) and, ultimately, energy transition as a whole.
The factors are linked to general trends of social and cultural change, since they are influenced by – and affect – change processes of transnational nature, such as migration, the ageing population, gender relations or changes in the governance of contemporary societies.

The complexity and nonlinearity of energy transition allows us to see the energy transition as composed of two main components:

- the first component is a process of technology transfer, centred on the introduction (identification, planning, activation, management, use, maintenance, etc.) of eco-sustainable energy technologies within a particular national or local context. This first component is defined hereafter “Technological Societal Process”;
- the second component is a political process that involves potentially all dynamics of a political nature (local, national, transnational), such as decision-making, adoption of standards, fundraising and management, or power relations between political and administrative levels. This second component is defined hereafter “Political Societal Process”.

Technological societal process for energy and environment transition

At the heart of the energy transition is a shift away from a system of energy technologies based on fossil fuels to one where energy from renewable energy sources is predominant and which achieves levels of efficiency and energy savings significantly higher than at present.

This transition, however, should not be seen as a mere technological process. Energy transition is more like a general process of technology transfer, in which each technical step requires action or has organisational, economic, social and cultural implications, often decisive in promoting or, conversely, severely restricting or even preventing the deployment of new technological solutions.

The elements that come into play are therefore very different, including social or organisational aspects closely related to the operation of the technologies introduced (technical support and maintenance, training for technicians and professionals, resistance from some of the stakeholders materially responsible for their introduction) and aspects that are seemingly less closely related but equally decisive for the spread of environmentally sustainable technology solutions, such as social acceptance, adaptation to local contexts and especially concrete absorption in the daily lives of individuals and families.

In sum, technology is undoubtedly a driving force in energy transition. However, this is only because it is transferable and is actually transferred, becoming an integral part of the social, economic and cultural context in which it is introduced. Outside this framework, there is the risk that new technology may be an element of separation and conflict or isolated from the dynamics of innovation and transformation that affect society as a whole.

Overall, for the Technological Societal Process, 17 constitutive factors have been identified, of which seven are enablers and 10 obstacles.

Enablers

1. Adapting technologies to social and environmental contexts
The experiences examined offer several examples of strategies geared to adapting new technologies:

- in one of the experiences analysed, solar panel technology – normally used in single family homes – was adapted in order to make it compatible with a very densely populated urban context characterised by condominiums. One example is that of adopting particular solar panels which could be installed horizontally on roofs (instead of vertically, as is normally the case) or with only a slight inclination, in order to minimize visual impact on the existing building’s appearance;
- in other cases, when selecting the technologies to be used, it was decided to privilege those that could make the most of local production potential. This was the case, for instance, with projects envisaging district heating systems powered by local agricultural
by-products (such as straw) or by products easily available locally (e.g. wood chip burners), with the dual effect of sustaining the local economy and cutting transport costs of fossil fuels;

- In many cases, this need was met by project promoters by establishing – already at the outset – cooperation with universities and research centres, and this enabled them to obtain advanced scientific knowledge for advice, opinions and evaluations geared to such things as project-designing or testing the energy efficiency of new plant and equipment.

- Finally, some experiences focused on introducing wind technology by making the most of a centuries-old local tradition of windmills.

2. Capacity building of technicians and professionals

Analysis of the anticipatory experiences led to identifying various examples of successful capacity building geared – depending on the situation – to architects (e.g. on designing solar panels and photovoltaic systems to be installed inside buildings), plumbing technicians (e.g. in setting up district heating systems) or electricians (e.g. in installing solar collectors, photovoltaic panels or small wind turbines).

- In several cases, the promoters introduced new professional roles such as “green planners” and “sustainability operators” in firms, “energy advisers” and “mobility managers”.

- In one of the initiatives, the local energy agency prepared a whole set of technical documents (including such things as a guide to drafting eco-sustainable projects and a manual for inspecting and evaluating installations) for a broad range of operators concerned.

This factor can play a key role, above all, if grasped in its broadest sense of scaling-up the initiatives geared to spreading eco-sustainable energy technologies, and is combined with broader transformation processes such as the adoption of institutional strategies for creating technological projects more attentive to the valorisation of local human capital, the production of a stock of technical knowledge at a global level and attention to the more immediately applicable aspects of research activity.

3. Link between local cognitive capital and global knowledge

A propensity to harmoniously link local knowledge with global knowledge was found in several initiatives.

- In many cases, this need was met by project promoters by establishing – already at the outset – cooperation with universities and research centres, and this enabled them to obtain advanced scientific knowledge for advice, opinions and evaluations geared to such things as project-designing or testing the energy efficiency of new plant and equipment.

- Still with a view to establishing links between the local and global sphere, some projects led to specific programmes geared to formalising and capitalising on the lessons learnt during the project itself or in other initiatives, particularly in the field of sustainable architecture. These programmes took the form of a forum in which the various stakeholders (national government, local administration, architects associations, developers, etc.) could discuss the outcomes of the various experimental actions implemented in constructing sustainable buildings and housing estates.

4. Technical assistance and maintenance

- One strategy adopted by some promoters (particularly by local administrations) to provide adequate technical assistance to plant and equipment is to set up energy advice centres, independently of the energy technology providing firms, in order to provide advice to citizens on what to do at home with regard to insulation, energy saving, and energy and heat production from renewable sources. This advice is often geared to guiding citizens within the complex picture of state and regional tax incentives.

- In other cases, the projects proactively tried to promote assistance services to firms, public utilities or local authorities in planning their own strategies for increasing energy efficiency or for producing clean energy.

- In the cases examined, there was also a propensity to set up preventive maintenance systems in order save time and costs in bringing broken-down equipment back into operation.

5. Flexible project-designing geared to complexity

The experiences analysed offer some indications on how this kind of project designing can be achieved.
In this regard, it is interesting to note the various actions geared to coming to terms with some phenomena emerging in the territory and society as a whole. For instance, many initiatives aimed at building eco-sustainable neighbourhoods that can house social groups and families with different needs (young couples, low-income and high-income families, immigrants, etc.) by offering a balanced mix of housing including free-hold properties, rented accommodation and council tenancies. Some of them were planned also with a view to prevent urban sprawling.

Some projects envisaged building homes to meet the needs, for example, of Islamic residents, the elderly with physical problems and the disabled. In other cases, “modulable” and flexible homes were designed which could be modified on the residents’ request.

Some initiatives particularly paid attention to citizens’ expectations (comfort, convenience, security, etc.). Examples of this are the various initiatives which introduced an urban traffic arrangement which could combine needs for mobility with those of comfort (elimination of noise) and road safety (especially for children).

It is also worth mentioning the many actions which adopted a holistic approach by developing project-designing methods that can consider all the variables concerned (quality of materials used, eating habits, refuse management, water use, ways of producing energy from renewable sources, energy saving in homes, mobility and transportation, etc.).

Some promoters followed another path: that of “reducing complexity” by adopting such things as already tried and tested technologies produced on an industrial scale in order to minimise maintenance problems and repair costs in case of breakdown.

6. Spreading of technological responsibility
Examples of the taking on of technological responsibility were found when analysing the anticipatory experiences.

A significant aspect, for example, was the proactive attitude of citizens in promoting, sustaining and implementing programmes geared to sustainability (such as, when defining and introducing new plans for mobility or in designing and implementing new procedures for differentiated refuse collection) as well as, in some cases, their direct economic involvement in supporting the adoption of new technologies.

Similar cases were found in some projects, and overcoming the initial resistance also with engineers and architects, who autonomously took on specific responsibilities such as in searching for new technical solutions, in spreading eco-sustainable technologies in the local market or in guaranteeing the validity and safety of new technologies for the general public.

Technological responsibility is undoubtedly something that must be grasped within a broader change of relations between science and society, and the search for new and more effective forms of governance of contemporary societies.

7. Continuous innovation
Many examples of continuous innovation were found in the experiences examined, in sectors like refuse disposal management (e.g., by using robots or underground automatic separation systems for differentiated refuse collection) the use of sustainable materials, the experimentation of biofuels, the construction of wind turbines for single family homes, heat insulation techniques or improvement of technologies for electricity and heat production.

Continuous innovation is also facilitated by more general trends in the way scientific and technological research is produced and by the consolidation of a broad set of global knowledge regarding eco-sustainable energy easily available to all.
Obstacles

1. Resistance to innovation by professionals and developers
   - In the research, widespread prejudice was found among professionals regarding the real effectiveness of thermal solar panels in energy saving. Further resistance was due to difficulties in including solar panels in one’s projects, which were difficult to integrate in the aesthetic and functional aspects of the buildings. In still other cases, the scientific community of architects had negative views on projects for building eco-sustainable housing estates.
   - As regards developers, their resistance was often due to the fact that they could not gain any benefit from introducing eco-sustainable energy systems in view of the installation costs, which were either covered by public subsidies directly granted to house buyers themselves or had to be included in the price of the home (thereby increasing the risk of the investment made). More generally, developers showed a certain difficulty in accepting or adapting to new standards (with regard to parking lots, spaces, materials, heating systems, etc.) imposed on them in the construction of eco-sustainable buildings and housing estates.

2. Citizen’s resistance linked to the search for individual and family autonomy
   - Examples of this kind of resistance were found in the case of residents of neighbourhoods with low environmental impact who were exposed to broad awareness-raising programmes on energy saving. These people showed behaviours such as increasing the use of electrical appliances and standby devices in the home, purchasing and using bigger cars with a higher fuel consumption, or by increasing the number of flights paid, at times, with money saved by reducing energy consumption. These behaviours must be interpreted as the expression of a strong trend towards autonomy, especially in view of the fact that they were widely found among people long exposed to awareness-raising initiatives regarding energy saving. Moreover, it must be noted that, in some cases, the increase in energy costs deriving from these behaviours was even higher than the saving obtained by the introduction of new energy technologies.
   - More explicit resistance was found in initiatives envisaging the shift to district heating or condominium central heating, where users who were used to their own independent heating system refused to connect to the new system.
   - These phenomena undoubtedly indicate broader and widespread processes of growth of individual subjectivity which, in turn, affect relations between science, technology and society.

3. Disagreement on practical solutions concerning the organisation of daily life (convenience)
   - The phenomena found in the project include protests against the low number of parking lots, the attempts made to get round the restrictions on car use, the re-conversion of mixed home/office buildings to simple dwellings on the part of owners, phenomena of “leaving one’s neighbourhood” either to go to big supermarkets and shopping centres (by car) or to spend one’s free time.
   - This obstacle is linked to the increased value people place on convenience in all aspects of social life.

4. Tensions linked to the protection of privacy and to individual and family security
   - The study found how some residents tried to guarantee their own privacy by putting up curtains in windows of passive homes, thereby reducing energy efficiency. Tensions linked to privacy were also found in eco-sustainable urban-planning initiatives which tended to favour a density of housing perceived by many residents as a limitation of their own privacy. Some technologies introduced were replaced because they were perceived – or actually were – dangerous to people’s health.
   - This obstacle, like the previous ones, expresses people’s more general concern for privacy and health, which is an emerging trait in contemporary societies.
5. Resistance due to essential needs for comfort and cleanliness

- It is possible to cite various examples of how needs for comfort and cleanliness are dominant for people compared to eco-sustainability goals.
- It was found how, in some cases, people used the special areas in a passive home that are dedicated to indoor and outdoor temperature compensation as normal rooms, thereby wasting heat and energy.
- In other cases, for reasons of cleanliness, people replaced their water-saving lavatories with more traditional ones.
- Finally, in various surveys conducted among inhabitants of new eco-sustainable neighbourhoods, the residents’ decision to move there was firstly based on aspects of comfort and only secondarily on environmental aspects.
- Despite being often neglected, this hindering factor may carry significant weight in the success of initiatives geared to energy transition.

6. Prejudice towards transition energy

- Prejudice towards eco-sustainable technologies was found in several anticipatory experiences.
- These prejudices (without going into how valid they may be) include: the idea that energy saving deriving from using solar panels does not compensate the energy needed to produce them in the first place; the idea that solar panels are unsuitable for urban contexts; fears concerning energy production from refuse; the belief that windmills are dangerous for birds.
- Further difficulties are linked to people’s resistance to invest in equipment for the production of renewable energy, certainly linked to poor knowledge of the subject (such as the legal and fiscal aspects), but also to the idea that investing in these technologies is complicated and risky.
- In some cases, paradoxically, there were even users’ excessive expectations regarding the performance of solar panels installed in their own homes (particularly as regards very ecologically-friendly panels).

7. Poor socialisation of technological innovation

- The study found some signs of a poor socialisation of technological innovation.
- These include such things as the absence, discontinuity or poor accessibility of technical assistance and maintenance services, the inadequate availability of installers for the new equipment introduced, and the poor quality of locally available technology supplies.

8. Presence of critical aspects and errors in project-designing

The project-designing difficulties and errors found in the study are of various kinds:

- problems in assessing the weight of citizens’ and users’ expectations with regard to such things as comfort, practicality, privacy or security;
- mistakes in forecasting some important trends (e.g., demographic trends in the area);
- critical aspects found when introducing the technology in the local architectural, environmental, social and economic context;
- project-designing errors (the wrong technological solutions; mistakes in project scaling);
- calculation errors in evaluating the effects of using certain construction materials on energy saving, etc.).

This phenomenon involves various more general dynamics linked to the management of science and technology, and to large-scale social and cultural transformations found in all contemporary societies.

9. Presence of critical aspects concerning the poor competence of technicians

The projects examined all concerned experiences of excellence and so there were very few situations of poor competence on the part of technical staff. However, some aspects can still be mentioned, such as:

- not using local personnel in the installation and maintenance of wind turbines owing to their lack of proper training;
- the failure of a project component envisaging the creation of a fleet of electric cars for local administration staff, owing to a lack of specifically trained local technicians;
poor knowledge of construction techniques for low energy homes on the part of engineers and technicians of the construction firms involved;
- the lack of jurists with grounding in dealing with environmental legislation;
- the poor training of locally available plumbers in operating on district heating systems.

10. Poor knowledge-management orientation
This poor orientation to knowledge management may come about in various ways.

- One particularly significant indication is the lack of development — on the part of project promoters — of specific actions geared to knowledge building and sharing [e.g., taking part in international networks, organising moments of internal or public reflection on the project, drafting evaluation reports and documents, establishing stable relations with other project promoters, etc.].
- Another indication is the absence of networks or moments of exchange and common reflection among the various actors involved in the project (public administration representatives, professionals, builders, etc.) as well as the lack of communication channels between the various administrative levels involved (so that the experiences achieved at a local level do not resonate at a national one).

The political societal process

In energy transition, politics is certainly no less important than technology.

How important politics is, in fact, can be easily understood. Energy transition involves all citizens, affects consolidated interests, challenges entrenched decision making and administrative routines, requires local, national and international investment which, without exaggeration, is huge, has profound economic impacts and is able to activate widespread and continuous forms of collective mobilisation.

Bearing this in mind, it is difficult to imagine that energy transition can develop without political decisions being taken at the right time, in the right way and in the right direction, involving key stakeholders, anticipating and interpreting demands from different economic and social sectors, keeping public attention focused on issues of eco-sustainability when it begins to wane, managing the conflicts that inevitably arise and facilitating public and private investment in energy transition.

Just as the technological process cannot be reduced to a mere matter of technical choices, neither can the political process be reduced to only a set of more or less effective policies.

A societal process that goes far beyond the single action of institutions and the range of individual programmes. It concerns, more generally, deep social and economic pressures, which cannot be handled by the usual decision-making mechanisms. New forms of governance need to be developed which are more articulated, flexible, inclusive and sophisticated.

Overall, 26 constitutive factors referring to the Political Societal Process have been identified, of which 15 enablers and 11 obstacles.

Enablers

1. Presence of leadership of adequate quality
The field study showed how this factor can have different features.

- Firstly, since they are experiences with high technological content, the technical capacity of leaders is particularly important. In general, managers of the initiatives examined had a solid disciplinary grounding and, in some cases, had already implemented projects geared to eco-sustainability. At times, in carrying out their tasks, they are flanked by a network of trusted professionals who have different specialisations.
- Another important element is the managers’ mobilisation and ability to convene others. Some, for example, as well as having technical skills, also have charismatic leadership qualities that can gather consensus around an initiative.
A third element that emerged is the continuity of project leadership commitment, sometimes even after the project is completed; this commitment reflects a more general inclination to militancy in the field of ecological responsibility (it must be said, in this regard, that some projects examined are led by managers who had, in the past, also been activists in environmental organisations).

These traits define a kind of leadership such as a non-routine one focused on commitment and personal motivation, and based on a far-ranging “vision” of the environmental issue which is still fairly unusual in public administrations.

2. Programming the political process

Some of the practices of programming the political process were identified during the analysis.

- One finding, in this regard, is the promoters’ propensity to adopt forms of “open” programming that can change over time depending on how the experience develops. After a pioneer phase (sometimes also ideologically oriented and normally with very ambitious goals), some initiatives were deeply reprogrammed to enter a more “realistic” phase, which allowed them, for example, to come to terms with real market dynamics, to establish intermediate goals enabling them to trace, step by step, more concrete transition paths or to better arrange the available resources according to priorities.

- Another important element is the adoption of explicit methodological approaches (approaches based on a constant link between action in the territory and research activities; strongly pragmatic problem-solving activities, even if not devoid of a general strategic orientation, etc.). In some cases, more than one approach was used, depending on needs (e.g., adopting a top-down approach when promoting demonstrative projects, and a bottom-up approach when implementing actions of great social impact).

- An important element emerging from the analysis is the presence, upstream, of clearly defined general political orientations which help, for example, to identify the priority social groups to be sustained, the behavioural models to privilege or the long-term goals to be pursued.

Programming the political process undoubtedly links up with a more general transformation of public policy management mechanisms, also with a view to governing the rapid changes (migration processes, ageing processes, changing dynamics of poverty and social exclusion, etc.) taking place in contemporary societies.

3. Citizens’ orientation to change

Examples of citizens’ active mobilisation were often found in the experiences examined.

- Sometimes, this positive orientation is favoured by specific circumstances such as the strong presence of highly educated people among the beneficiaries (normally more sensitive to environmental issues) or of a tradition of local environmentalist mobilisation.

- In other cases, the emergence of a positive attitude to change is brought about by the project itself, such as by getting citizens to become co-owners of the new technological plant and equipment (thereby encouraging a widespread feeling of project ownership among the population).

- A comforting finding, above all with regard to the future, is that almost all the promoters of the initiatives examined found a significant and generalised growth in people’s awareness of eco-sustainability issues over the last few years.

The key point is that those involved in promoting eco-sustainable initiatives have to know these dynamics and to know how to effectively identify and involve the more active social actors, bringing them over “to their side”, so to speak.

This means, especially on the part of public administrations, having a capacity to interpret reality which constitutes one of the fundamental elements of institutional transition currently under way in all advanced societies.
4. Other actors’ orientation to change
As with citizens’ orientation to change, here, too, a tendency to mobilise may be due to various reasons.

- One of these is, obviously, the prospect of obtaining economic benefits [such as with construction firms] or of having commercial and image benefits [as with firms supplying and installing the new technologies introduced].
- Another decidedly important aspect is the creation of a “strong” and convincing vision, which the different actors can identify with, of the possibility of establishing a post-carbon society, as well as the determination and will of local political forces to support the project by putting forward their own credibility with respect to the electorate.

5. Citizens’ active participation in the energy transition
There are many examples of participative practices.

- One widespread tendency is that of triggering forms of co-decision with citizens during the planning stage, by using instruments such as setting up workgroups, a standing consultation forum or focus groups in the various neighbourhoods.
- The study also found autonomous forms of lobbying with local authorities in order to adopt sustainability measures on the part of organised groups of users, associations of residents of the new eco-sustainable housing estates or environmental NGOs.
- In other cases, citizens, organised in co-building groups, participated in the technical design of their own homes, of new energy systems to be fitted in their homes or of the solutions to be adopted at a neighbourhood level [such as regulating the use of private cars].
- Participation also takes other forms such as citizens’ co-financing of the project [e.g., of waste management plants, solar panel or district heating systems], by setting up cooperatives or joint stock companies, or the taking on of specific responsibilities in its implementation [as is the case with NGOs and neighbourhood associations involved in training and awareness-raising initiatives on the use of new technologies or in parking lot management].

This widespread citizen commitment in planning, project-design and implementing actions has another important effect; it orientates projects towards the needs of weak subjects or specific social categories, such as youth, immigrants or the elderly.

6. Building consensus

- The main practices studied for this constitutive factor focus on negotiation mechanisms activated at various levels. In the early stages, the negotiation actions mainly sees the institutional actors involved [local authorities, public financing agencies, electricity boards, decision-making bodies and committees] and later firms called upon to implement the project [construction firms, plant and equipment firms, consulting firms, etc.]. Later still, the negotiation process tends to extend to beneficiaries, involving users, civil society associations, economic lobbies and the general population.
- The tools used differ considerably depending on the circumstances, and include such things as the creation of consultancy networks between construction firms, local authorities and developers, the implementation of public consultation initiatives, the opening up of talks between project developers and other stakeholders or the creation of workshops and informal meetings.
- A widespread approach to facilitate consensus building is to carry out demonstrative actions and pilot studies [such as building a first group of passive houses to show the general public or installing solar panels on public buildings with great visibility such as post offices or sports centres] to persuade decision-makers, financiers or potential users not just of the positive impact of new technologies on the environment, but also of the benefits that citizens themselves can gain from their introduction [in terms of things such as the reduction of management costs or an
increase in the quality of life). The various kinds of demonstrative actions are thus determinant also to overcome prejudice and stereotyping with regard to new technologies.

7. Public communication and awareness-raising
- Anticipatory experiences show that communication circuits and networks, at various levels, tend to develop around eco-sustainable initiatives, owing to the actions of promoters and other stakeholders.
- These circuits and networks are based on various communication tools (web TV channels, online newsletters, exhibitions, guided visits to technological sites, press campaigns, house-to-house visits, etc.) and are characterised by differentiated language forms (from technical to general, and from those linked to daily communication practice to those of greater symbolic impact).

All this leads one to think that communication will play a decisive role in making the transition towards a post-carbon society socially manageable. This factor lies within a more general trend of giving increasing weight to communication in the construction and implementation of public policies, especially when they have to do with important scientific and technological decisions.

8. Starting up a networking system
This constitutive factor takes on different forms and moves in various directions.
- For example, to give strength to their own decisions, some municipalities join international networks of local bodies involved in promoting renewable energy.
- In other cases, informal networks of residents are set up to favour project management or networks of different local bodies involved (e.g., those lying within the metropolitan area concerned) in order to favour more effective coordination in dealing with common problems and to exchange more effective solutions.
- In still other cases, informal networks were created at the citizen level, including all those who had previously been involved in energy renewal themes, such as professionals, academics and environmentalists.

- This networking activity sometimes has an institutional character (in the form of consultation panels, workgroups or coordination committees) to facilitate discussion between all the groups concerned (local bodies, local electricity boards, consumers, construction firms, researchers, technicians, professional associations, etc.) in order to orient decision-making, prevent conflict and overcome organisational and technical problems that can arise from time to time.

The tendency to accompany policies with intense networking activity, both in the local and international sphere, reflects a more general process of institutional transition (driving towards broader and more complex forms of coordination in public policy management), but also expresses a strong drive towards a globalisation of knowledge, not only of a technical or scientific nature, but also concerning the promotion, management and evaluation of public policies (in this case, in the energy field).

9. Capacity building of citizens and of public administration staff
The target and contents of these actions varies a great deal according to the kind of project implemented.
- For example, in the case of actions focused on a broad dissemination of new heating systems among the population, there were always training activities (seminars, meetings, handing out of manuals, etc.) for residents on the use of new equipment, energy saving and the adoption of more environmentally compatible lifestyles.
- In some cases, these specific activities were accompanied by more general actions of environmental education (such as courses for children in the neighbourhood schools).
- The capacity-building initiatives were put forward and implemented not by the promoters but autonomously by organised groups of citizens.
- Almost all the actions focusing on the construction of new eco-sustainable neighbourhoods also envisaged the creation of a centre for information, training and assistance that was easily accessible to residents.
There were also actions geared to specific groups of citizens (such as linguistic minorities).

A great many capacity-building activities were also aimed at local public administration personnel in order to improve their technical skills so that they could be of greater support to the community.

This intense use of capacity-building is also common to sectors other than the environmental field, above all, the tendency of public administrations to improve their own action by focusing on human capital, and users’ tendency to take on an active role in scientific and technological innovation processes.

10. Creating an adequate and flexible regulatory framework

The eco-sustainable project promoters seemed to focus on clusters of detailed legislation in which, alongside very clear and binding general principles and norms, forms of regulations are produced which are more sensitive to changes and more flexible in their implementation, as reference standards that can be improved over time, simplified administrative procedures, instruments for coordinating the norms produced by the various levels of government or quicker and adaptable norm updating mechanisms.

While, on the one hand, the experiences examined showed the importance of imposing rigorous measures, above all as regards aspects like energy consumption, construction criteria for new housing or greenhouse gas emissions, on the other they showed how it is equally important to adopt a problem-solving approach which makes the inclusion of these very restrictions feasible, thereby meeting the needs of the various actors concerned.

These trends seem to reflect a broader need to provide public policies with legislation enabling them to come to terms with the growing complexity and speed of change that characterise contemporary societies.

11. Functioning of an integrated networked fund-raising system

According to anticipatory experiences, this constitutive factor is concretely achieved in different ways, such as by:

- exploiting fund-raising opportunities offered by big events (trade fairs, sports and cultural events, etc.);
- activating investment programmes at municipal level and specifically geared to the project;
- taking advantage of existing energy sector deregulation policies;
- adapting the project in order to access funds destined for other uses (e.g., funds for technological research and development);
- promoting policies geared to encouraging the private sector to invest in certain aspects of the project;
- grasping and exploiting the various funding opportunities offered by the European Union.

Here, too, there is a tendency which, in the eco-environmental field, appears to be at a particularly advanced stage, but is also found in other spheres requiring great public investment in technology and infrastructure – investments which no government or local body can guarantee on its own.

12. Decision making

The most common decision-making strategies envisage concentrating the entire responsibility for energy policy management in just one organisation (creating an ad-hoc agency that is independent of other administrative bodies) and creating a political-institutional post (e.g., a municipal councillor) that acts as the sole point of contact for all the actors concerned. The idea is to keep control of decision-making and avoid delays, the conflict of responsibilities or misalignment among the various decision-makers.

These are decisions which, especially when grasped with a view to the scaling-up of eco-sustainability policies, can pave the way to new forms of institutional transition, also in sectors other than the eco-environmental and energy one.
13. **Adopting a high quality management system**

The anticipatory experiences examined offer a vast, and not necessarily comprehensive, array of **tools and approaches** geared to maintaining high quality management.

- One recurrent strategy is to strengthen and extend the **monitoring and evaluation** of actions under way and to systematically adopt forms of **certification** for both technological installations and the installing firms themselves.

- Moreover, various projects create their own quality system starting from a “**holistic**” approach to **evaluation** which takes all the variables involved into account (not just eco-environmental ones, but also economic, social and cultural ones) as well as all the “dimensions” (local, national and international) which come into play.

- Another aspect which is considered important in quality control is the fielding of tools geared to the systematic gathering and interpretation of **information** on the action and its impacts (such as that concerning energy efficiency of the equipment installed, price trends of the various energy sources used and produced, the degree of user satisfaction or the development of energy consumption).

14. **Self-reflexivity and applying lessons learnt**

In the anticipatory experiences analysed in the study, the capacity for self-reflexivity and for applying lessons learnt is very marked.

- Some actions, for example, were conceived from the outset as characterised by a **gradual scaling-up process** enabling a shift from one dimension to a larger one by screening the best solutions in order to reproduce them in the next stage.

- Another practice used was to glean a **series of reference standards** from the experimental projects implemented (such as construction standards, management standards, reference values regarding emissions and energy efficiency) to apply on a broader scale: neighbourhood, town or national level.

- There was also a strong commitment to turn the experiences into **success stories and best practices** to disseminate (the internet plays an important role in this regard), as well as in exchanging experience, information and practice among eco-sustainable project promoters, by creating associations and networks linking all those working in the field.

This phenomenon links up with a more general orientation geared to improving the way public administrations and political leaders design and develop public policies – an orientation that is certainly favoured by a strong globalisation of knowledge even in the energy sector.

15. **Social, cultural and economic impact**

The nature and dimension of the impacts varies considerably according to the characteristics and contents of the actions implemented.

- The impacts mostly recorded include those of an **economic nature** (creating new jobs, increasing the value of homes affected by the project, creating or strengthening the economic sectors linked to the environment).

- However, even **social impacts** are important (reducing poverty and, in particular, fuel poverty, increasing social cohesion, improving the lives of disadvantaged people) as are, more rarely, **cultural ones** (for example, a revitalisation of the neighbourhood’s cultural life).

**Obstacles**

1. **Resistance in public administration**

- Conflict and resistance can concern **specific aspects**, even if not marginal ones, such as establishing the energy consumption parameters to apply to new constructions or introducing meters in homes in order to assess the exact energy consumption of individual families.

- In other cases, resistance relates to the **general framework of the project**. A significant example, in this regard, is an initiative in which municipal officials responsible for territorial planning showed great resistance to the introduction of passive houses, envisaged by the project, thereby coming into conflict with local civil society organisations which were decidedly in favour of their introduction.
2. Resistance by political forces

- A typical case of resistance by political forces is that seen following changes in the government in local administrations in which the new administration questions the eco-sustainable projects started by the previous administration, thereby causing – at best – setbacks in implementing the activities started or a situation of uncertainty that may be protracted over time.

- In other cases, the political forces – perhaps for fear of losing consensus among the electorate – show a tendency to avoid “hard” but necessary decisions and oppose the introduction of binding measures or, when they do have the power, they make existing ones only of a general kind (e.g., restrictions on car-use).

- There is also a certain attitude on the part of political forces to avoid resorting to participative approaches and forms of self-governance by citizens (perhaps because they limit the sphere of action of political parties) or to be suspicious of innovation not directly promoted by the administration.

3. Opposition from movements and citizens

Forms of opposition from movements and citizens were found in many anticipatory experiences examined, despite the fact that they are experiences whose excellence is widely acknowledged.

- In some cases, the opposition concerned the initiative per se (and thus the very introduction of new technologies) or the way it was designed. It must be noted, in this regard, how some types of technology have been the object of negative representation which has favoured the emergence of widespread resistance. For example, wind turbines are considered noisy and an eyesore, biogas plants noisy and smelly, and solar panel systems eyesores and not very efficient.

- Not infrequently, and sometimes paradoxically, it is environmental movements themselves that oppose the project (such as when it envisages the construction of new buildings and infrastructure that these movements deem unnecessary).

- In some cases, citizen opposition arises out of the fear of being forced to make investments which, in the citizens’ view, could be avoided. In the case of a project to increase insulation in private homes, for example, there was great opposition by owners who had rented their homes to others and therefore did not want to spend money on something they would not benefit from directly.

4. Legal and administrative difficulties

Legal and administrative difficulties include controversy over the interpretation of existing legislation (often not designed for projects of great complexity such as those linked to energy transition).

- In one of the cases analysed, for example, there was tension between public bodies over the attribution of responsibilities for maintenance of the new technologies, while in another case there were uncertainties over the inclusion of “environmental” clauses in contracts tendered to construction firms (some considered these clauses legitimate while others did not).

- Other difficulties arise owing to the overlap of national, regional and local laws, which are not always in sync with one another (e.g., as regards the ratio between parking spaces and residents, the procedure for installing low energy systems in homes or criteria for establishing urban development plans), with contradictory effects (such as the impossibility of applying a standard, not because it has not been defined, but because more than one has been established by various administrative levels).

- There were also more specific difficulties such as problems in guaranteeing control over the application of new laws (also owing to a lack of resources) or the difficulty in identifying legal and administrative procedures to new standards binding (and thus really effective).

5. Poor control over costs

Some of the anticipatory experiences examined in the study experienced many problems in this regard.

- The most frequent is the difficulty in coping with high initial investment costs – a difficulty derived not just from objective factors, but also from the poor capacity to forecast amortisation periods with any degree of certainty (since they are innovative technologies with a still limited market).

- The risk that many operators note is that these costs end up falling almost completely
on public bodies, whereas – to help speed energy transition processes – investments should come directly from private investors, within a market dynamic.

- On the other hand, even the common solution of **placing the initial investment cost on users** is not always effective. In the absence of incentives for buyers, selling low energy houses at a higher price (5-10% more, and sometimes up to 20-30% more) has led to lengthy sale periods and consequently to delaying the initial investment’s amortisation period.

- Even the decision of some governments to tax (or not to exempt from tax) post-carbon solutions (such as biofuels) is a disincentive.

This issue can have considerable social consequences since, due to the scant cover of the initial investment, the **poorest families** cannot access eco-friendly technologies and find themselves, in the end, exposed to fluctuations in non-renewable energy prices.

6. **Difficulty in accessing funds**

- The study showed how some projects receive little contribution from **national and local funds for project implementation**, also due to legislative constraints (such as those preventing local bodies from increasing local taxes beyond an established limit) or spending limit mechanisms (such as the suppression of funds destined for council housing).

- Access to funding is also negatively affected by other elements such as **uncertainty over procedures** to be followed to obtain financing (often not clearly defined, not completely transparent or subject to change during the process), the **caution of credit institutions** towards technologically innovative projects or **delays in providing** already granted funds (above all, owing to obsolete bureaucratic procedures not specifically designed for eco-sustainable energy projects).

7. **Undesired effects of user selection**

- One effect found in some of the anticipatory experiences studied was, for example, that of **[involuntarily] selecting citizens and potential users according to their purchasing power**. Low-polluting technologies cost more and so, without any subsidies or effective incentives, they risk being inaccessible to low-income families or even, at times, to middle-class families. Because of this, some new eco-sustainable neighbourhoods, for example, have decided to attract mainly families with a decidedly higher income, thereby becoming social “eco-enclaves”, so to speak.

- This phenomenon may be facilitated by **involuntary selection mechanisms** paradoxically stemming from citizens and users’ demands for **active participation in eco-sustainable project planning**. For example, it was found that the participative approaches adopted sometimes tended to keep certain groups, such as the elderly or disabled, away, so the project was planned without considering these groups’ needs. Similarly, cases were also noted of immigrants not being included in decision-making owing to language barriers not adequately taken into account by project promoters.

8. **Poor capacity to control energy performance and system quality**

- More than a strictly technical problem, this obstacle stems especially from **organisational or cost factors** which lead to **not adopting the necessary measurement tools** (such as for measuring the additional hot water produced by solar energy systems installed in support of traditional heating systems) – which prevents users themselves from understanding just how much they are saving, and technicians from evaluating whether the systems are working properly.

- Difficulties were also found in **quality control of plant and equipment**, also for organisational and cost reasons. This problem, in particular, was found not in relation to individual systems but in installations – such as in passive houses or other kinds of low energy homes – based on the simultaneous use of different eco-sustainable technologies

9. **Shortcomings in the circulation of technical, social and political information**

**Shortcomings in information circulation** were also found in some of the anticipatory experiences
examined (which, it should be recalled, are all experiences of excellence in technology transfer management).

- In some cases, users were not informed of the existence of the new technology, the benefits it could bring, the way it worked or the care to be taken when using it. This phenomenon concerned, for example, condominium administrators in buildings in which solar energy systems were to be installed, the potential residents of low-energy houses, but also firms, hotels and public bodies such as schools and postal organisations involved in heating system restructuring projects.

- Communication problems were also found in relations between the actors directly involved in project implementation (e.g., between different administrations or between administrators, construction firms and technical personnel), as well as in relations between project teams and beneficiaries (in these cases, for language and cultural reasons especially).


- A recurrent problem with this obstacle, for example, is the general difficulty users have in “learning to use” passive houses – a difficulty that was also found when they were given specific aids and manuals.

- In particular, similar problems concerning the lack of users’ autonomy were found with the introduction of technologies like ventilation systems in low energy homes, waste recycling management, water recycling equipment, routine solar panel maintenance, also due to the non-activation of proper training and capacity-building measures on the part of project heads (PE9).

One of the consequences of this state of affairs is that people find it difficult to make the new technology “their own”, above all because they continue to depend on technical personnel to carry out the simplest running and maintenance operations (such as closing the taps of hot water produced by district heating systems).

11. Low priority given to energy saving by public service providers

This is still a marginal phenomenon, but could gain increasing weight within the broader horizon of energy transition. In this regard, one should consider how public service providers are often indicated as actors that could act as engines in spreading new energy technologies (it is not by chance that they are sometimes the first to get involved in demonstration projects). Their resistance to investing in eco-sustainable energy is thus a “bad sign”, even for the population. Moreover, we should not overlook the fact that one of the sectors in which energy eco-sustainability is promoted is with “large-scale consumers”, including public service providers. Their poor mobilisation can thus lead to considerable setbacks on the road to a post-carbon society.

2.3.2 | Perceptions, fears and trust of European youth

The developments described below are based on the results of the research carried out by the University of Padova in the first phase of the PACT project[108].

A survey of European youth

In the framework of the PACT project, a survey targeting young people (mainly secondary school-age) was organised across Europe. It had two main objectives:

1. to identify, in view of the various agencies of socialisation (family, peer groups, school, other) which are the most formative in terms of credibility as seen by the young interviewees based on their socio-demographic profiles;

2. to identify scenarios for future life (desired and expected) that European teenagers imagine in their transitions to adulthood and to a post-carbon society. Related to this, we aim to understand what role the interaction between social capital and human capital

plays in the representation of future scenarios, as well as the socio-cultural variables that influence the creation of differences. In the definition of future life scenarios, the focus was put both on the ability of young Europeans to envisage a time when oil sources will be exhausted as well as the alternatives that will replace them, and the various aspects of daily life (transport, work, entertainment, interpersonal relationships, etc.) which will be affected as a result.

How do young Europeans see the conceivable end of oil, when it will run out and what will substitute it?

What awareness do young Europeans have regarding the limited supply of energy sources in their daily lives? How do they imagine that such changes might affect their way of life? Are they well informed on the subject?

How do young Europeans see the future in terms of values and problems in a risk society? What risks do they perceive and what kind of protection do they imagine?

What areas of public life interest young people and how does this translate into a hypothetical plan for tomorrow?

Who do young people trust regarding the future? Are political figures seen as credible or do young Europeans trust other figures more? Does mobility represent a real or simply hypothetical view?

The questionnaire, entitled “Youth, Energy and Future: Pathways for Carbon Transitions” was composed of 4 sections:

Section 1: you and your personality (school, values, personality);
Section 2: the future that you imagine;
Section 3: the future that you would like;
Section 4: socio-demographic data about your family.

During a period of six months 4,186 completed questionnaires were collected, further 621 were not completed and thus not considered valid. 92% of the questionnaires were completed in a school context, 2% were begun in a school context and finished elsewhere, while 6% of those interviewed responded in an independent manner, presumably from home. The aggregate data shows the participation of 42 schools with 187 classes involved in a large number of EU countries with the original target countries of the investigation well represented.

The detailed interpretation of the surveys can be found in PACT. In what follows here, we present an overview of the main conclusions.

Misinformed and fearful about the future post-carbon society

Interpretation of the survey

A first specific objective related to the future life scenarios for young Europeans concerns the link between humans and the environment according to indications expressed by the sample of young interviewees. Through the questionnaire, we developed a first explanation of the notion of an end to the society in which oil is available and used. Related to this are questions concerning the possible limits of an era dominated by oil and, according to this premise, a suggestion of alternatives to imagine a transition to a different scenario.

The hypothesis we developed tried to gauge sensitivity to this view: insofar as the issue seems remote, it was presumed that a low awareness would allow a deeper examination of the theme, as well as suggestions for alternative energies. This interpretation reflects the intuitions of Heinberg [who introduced the concept of a post-carbon society], which were adopted in the preparation of the survey in a way that would be sensitive to recognising the interviewees’ behaviour and to their imagining a future energy change. Such sensitivity refers to the information available to interviewees. However, we believe that it is influenced above all by the young people’s cultural context and their daily lives.

The second part of the environmental issue is seemingly more shaded and transversal. A group of specific questions investigates the consequences of a lack of oil in an explicit and implicit manner; translating these consequences into the lifestyle of the young people interviewed. This
meant evaluating their awareness of the environmental impact of a lifestyle that they probably take for granted. The questions covered different forms of energy, and underlined the characteristics of young people’s current lifestyle in a consumer society.

The aim here was to evaluate whether the presumed lack of knowledge among young people regarding eco-sustainable lifestyles is present and rooted, beyond fashionable and stereotypical notions.

We dedicated particular attention to the possible contradictions between explicit appeals for the environment and declarations of interest regarding the impacts of lifestyles on environment and the lack of attention to other areas connected to lifestyle in our industrialised, oil-centred society.

Then we considered the problems and concept of risk according to the young interviewees. The risk society, as defined by many contemporary authors, is characterised by self-imposed risks, derived from the evolved ability of social auto-transformation. Therefore, as mentioned by Turner (1978), risks are generated by the (presumed) possibility to govern the natural and social environment.

Paradoxically then, awareness, not ignorance, is the source of risk. In this context trust can be defined as a positive aspect, based on cognitive and emotive measures, formulated in uncertain conditions. It is a useful ally for minimising the complexity of the future. Trust, therefore, can be seen as a substitute for uncertainty which allows us to take a course of action based on an uncertain result. The hypothesis is that young men and women are absorbed in the present and think little about the future. In these terms, risk in the sense of manufactured (“self-produced”) risk, as affirmed by Giddens, is a fact of daily life. They are accustomed to living with it and therefore neglect or consider it in some way unchangeable.

The type of society in which we live determines the way we imagine routes to possible future scenarios. Once we picture these routes, we can move towards examining the economic reality.

The hypothesis is made that economic investment should be coherent and convergent with the scenario imagined in advance so that people react accordingly. It is particularly interesting to consider the differences among countries based on the assumption that behaviour varies according to the young people’s cultural and historical background. These investments, it is presumed, are conditioned by lifestyle and existing conditions in the various countries, and the significance apportioned to various themes shows what is of most interest to the young people, but also that areas with similar investments represent those of interest to the young generation. Among these are environmental and ecological themes. This was used to gauge the young people’s level of interest in the environment.

The concept of trust was introduced with reference to types of individuals to whom European youth would wish to entrust the future of the planet. This subject is quite close to our target group and the young interviewees would point out the people present in their daily lives, traditional political figures and representatives linked to their country or detached from it. This part was especially interesting in relation to the hypothesis of a declining interest in politics as well as the extent to which young people are more and more detached from traditional politics. Therefore a divide can be spotted between individuals linked to knowledge and ideas, such as doctors and scientists; other individuals linked to the world of action: teachers, police, students but also entrepreneurs and consumers; and traditional figures of institutional power: political parties, judges and the clergy. We can make a further consideration regarding the confluence between this view and the value attributed to the state, the market and civil society, observing the extent to which a proposed leader represents traditional symbols.
of our capitalist society or other sections of society more closely connected to daily life, and whether a leader is thought necessary.

Finally, it is worth noting that some countries are considered more trustworthy in ruling the planet than others. We therefore evaluated whether the perception of those seen as more credible resembles the current situation. In this respect we hypothesise a possible diversification of strategies from high and tactical actions of the single person, confirming the intuitions, even though already consolidated, as proposed by M. de Certeau([112]). Such suggestions are presumably correlated to the scenario which we could describe thanks to analysis in previous areas.

Conclusions
The survey has shown that the hypothetical exhaustion of oil does not seem to worry young Europeans who see the eventuality as sufficiently remote not to impact their daily lives or interfere with their habits and experiences.

The youngest, born and raised in a time of uncertainty and risk, showed the most detachment and the least fear. On the one hand we can imagine them “surfing to the future” with an attitude that sees them already aware of a context characterised by continuous change educating them to adapt to instability, which they perceive as normal and therefore do not worry about. On the other hand they are immersed in their present and incapable of imagining alternative future scenarios.

“Older” individuals (over 16) tend to view the end of oil as shorter-term possibility (within 50 years) and demonstrate an ability to foresee different scenarios which are almost entirely negative. Even when they proved capable of identifying alternatives, these seemed to be more the results of slogans than realistic lifestyles. Some regional exceptions were observed: in France, for example, where young people demonstrated great awareness and sensitivity.

In relation to countries “guilty of pollution”, young people tend to turn their attention towards those outside Europe, identifying the two giants of world capitalism. The same is evident in their selection of possible “saviours”, as they reiterate the role and importance of the US. This could show a distancing from environmental issues due to a lack of sensitivity and knowledge.

The young people interviewed placed great trust in science and knowledge. Young Europeans feel that they can entrust scientists and doctors with the future. They see that knowledge and education represent important resources for the years to come. The appeal to knowledge in the daily lives of young Europeans is therefore strong as it is seen as interesting and useful to those who possess it besides something that young people can aspire to. The EU is also identified as an institution worthy of trust.

The centrality of school in the life of young Europeans

Interpretation of the survey
The value attributed to human and social capital is central to our analysis as it sheds light on the various abilities, competences and social relations that constitute young people’s profile as well as the influence of their conception of a post-carbon society.

Three dimensions of capital were revealed through questions about school, values and socio-relational context derived from networks both real (parental, peer, neighbourhood) and virtual.

In other words, the objective was to reconstruct both the role attributed by young Europeans to school, as the principal agent of socialisation, and the role played by values in their daily life, including those of relational networks.

Human capital was revealed by way of:

- academic achievement, understood subjectively (the student’s opinion) and considered objectively (the opinion of the teacher);
- the revelation of sectors in which it would be possible to profit thanks to school education (work, daily life, family, friendships and social relationships);
- the understanding of the priorities which young people think schools must have (“to provide an adequate number of competencies”, “to provide the ability to know how to live together and collaborate with others”, “to help the student perceive a meaning in their own life”).

Among the findings of these three categories we can see that that a “cushion” composed of values with which young Europeans identify (on a scale from 1, not important, to 5, very important) emerges from the social capital. The aim was, to reconstruct the values universe \((113)\) of young Europeans in a way that gives meaning to their actions, not only in the educational sense but in the broadest social context. We can therefore expand the scope of the investigation to social capital \((114)\), no longer focused on the individual’s relationship to the school or to his values system, to put him/her in context within his/her socio-relational universe.

The survey data obtained about “networks and social relationships” can be subdivided into two aspects: social capital (whether real or virtual) and territorial capital. These distinctions require some clarification. Territorial capital represents the bonds that subjects feel to the neighbourhoods where they live. If, therefore, on one hand territorial capital has an associative relationship compared to social capital, for the argument of relations/bonds which will be studied, it presents its own specific connotation because it has to do with daily reality, lived within a geographically limited space understood as an extension of the domestic space which is the central fulcrum of family relationships. In this respect attention was principally given to the evaluation of the degree of trust placed in neighbours and on the comparison between the networks of neighbourhood relationships and those of the family.

Moving away from territorial capital we can now explain how the quantity and the quality of the relationships young people build in their daily lives was revealed within society. Here trust (from 1, no trust, to 5, a lot of trust) dealing with family and friendships (family members, friends, classmates, neighbours and teachers) is the main concept. It is revealed that there are many people, part of both the family circle and friends, in whom subjects can place their trust, when necessary. However, it should be noted that the geographic location of these contacts revealed direct connection with the interactions in their daily life (in the neighbourhood, outside the neighbourhood but within the city, outside the city but in the same country, and finally outside the country). Finally, the analysis of virtual social networks was also studied. Young Europeans were asked

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if and in which online social networks they participated (especially Facebook, Myspace, etc.) as well as how frequently they did so (from once or twice a month to several times a day).

Connected to the social dimension of capital, a part of the analysis dealt with civic commitment, looking at youth participation in voluntary work in order to study the motivations behind this choice or breaks for not getting involved in non-profit activities. Alongside this, the collection of data on the number of associations young people joined and the sectors in which these associations operated (religion, politics, sports, health, social assistance or charity, culture, leisure or tourism, environmental or animal protection, safeguarding/promoting human and social rights) was studied. This permitted an attempt to construct the values that inform the behaviour of young Europeans as well as the social-relational context in which these value patterns are formed and maintained.

Conclusions
The information gathered throughout the survey confirms the central role of school for young Europeans. They consider it a midpoint in the journey between their daily lives and their future adult lives. School is not simply an arena that young Europeans see as legitimate in shaping their educational journey. Education is still considered as a springboard from which to build a future and transition towards adulthood. As such, it represents a vehicle for awareness campaigns about the opportunities and risks associated with a post-carbon society. In addition the students, especially boys, credit school as an important aid in their search for the “deep meaning of life”.

Of course, family and friends, too, have a strong impact on the way that young people view the future. They describe the importance and value of friendship, which is typical for this age-group, and underlines the importance of peer groups in establishing teenagers’ identities. School is seen as a facilitator that supports the web of their relationships, although this does not imply that young people lack social relationships outside school, or see school as the only arena for socialisation.

To conclude, school represents not only a bridge across which we reach adulthood, no longer and not only in terms of work, but also plays a role in building our future social network and constitutes the junction at which we comprehend the complexity of the changing cultural scene. We can thus consider school as the epicentre for educational projects aimed at the adolescents of today’s carbon society, on their journey to becoming adults of a post-carbon society.


2.4 | Chapter 4

History and meaning of the 2°C target policies

2.4.1 | Origins of the long term climate targets in Europe: Factor 4 or 80% reduction in 2050

Before the first oil shock, the Club de Rome first alerted the international community on the unsustainable character of an unlimited growth in resource consumption. Building on this intuition (first formulated in 1968), the Club pledged to aim at a less resource-intensive economic growth. It published a report – “Factor 4: Doubling Wealth – Halving resource use, a special report to the Club of Rome” ([117]) – intended to show that resource productivity can increase at negative costs. The lead author of this book is now in the process of editing a new one in which he encourages world leaders to seek to attain a factor 5.

The title of the first manuscript has survived, as has the idea of decoupling growth from resource use. Most studies focusing on sustainable growth still implicitly or explicitly consider that wealth can – and should, for most people – increase, whereas resource use should decrease. However, the object of the reduction is no longer resources by themselves, but rather the waste associated to the use of fossil energy resources, i.e. CO₂ emissions and more broadly speaking all GHGs. Another major shift in usage of the term is that the reduction considered is no longer relative, as set out in the Club of Rome Report, i.e. the carbon content of growth, but absolute: the division by a factor 4 of emissions relatively to a reference year.

In 2003, the French president and prime minister have made the first political formulation of the terms factor 4 along the lines detailed above as they were addressing an audience at the opening of the 20th plenary session of the IPCC in Paris. Jacques Chirac expressed the need to “…divide by two GHG emissions on a worldwide scale”, which for France translates into “…a division by four or five. With respect to the principle of our common but differentiated responsibilities and capabilities, we must show the example in implementing domestic policies aimed at mitigating the Greenhouse effect”. There is currently no explicit mention of the factor 4 objective at international level. However, the ambition of halving global emissions by 2050 has been officially repeated a number of times in different forums. World leaders consented at the 2008 G8 meeting in Hokkaido, Japan, to seek to halve global emissions by 2050, in particular through contributions from all major economies, in a manner “consistent with the principle of common but differentiated responsibilities and respective capacities” ([118]). This declaration implicitly recognizes the scientific foundations of factor 4, as we will show in the next section. Individual countries and geographical zones have additionally announced objectives consistent with or close to a reduction by a factor of four or five of their GHG emissions. Among these one can identify:

- the UK: since 2008 the UK policy framework has been underpinned by the Climate Change Act, which has two major targets: a legally binding target of 80% reductions in emissions in 2050 compared to 1990 and a medium-term target of a 34% reduction by 2020;
- Germany: In September 2010, the German government launched the “Energy concept”.
  According to this Plan, the greenhouse gases should decrease progressively and reach à 40% reduction in 2020 and a reduction of 80-95% in 2050. The renewable energies in the primary energy supply will be 60% in 2050;
- the Netherlands: In 2009 some climate protection policy goals has been identified by the central government of the Netherlands through the

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Letter of 8 September 2009 to the Dutch Parliament, “Tweede Kamer”, which proposes a 30% reduction of greenhouse gases in 2020 compared to 1990. Although it has not committed to any specific target for 2050, the Dutch government has published, through its environmental agency, a report defining a set of trajectories compatible with various GHG emission concentrations. This report recommends adopting a target of 450 ppm CO$_2$eq in order to safeguard the likelihood of keeping global warming below 2°C.

- the European Union: In January 2008 the European Commission proposed binding legislation to implement the 20-20-20 targets. This “climate and energy package” was agreed by the European Parliament and Council in December 2008 and became law in June 2009. Two major projects where promoted recently in the EU: the proposition of the European Commission to move from a 20 to 30% emission reduction target [May 2010] and the “Roadmap for moving to a competitive low-carbon economy in 2050”. The Roadmap sets a plan to meet the long-term objectives of reducing domestic emissions by 80 to 95% by 2050. It shows how the sectors responsible for most of Europe’s emissions, as the power generation, industry, transport etc., can achieve the transition to a low-carbon economy over the coming decades;

- the US, which made a pledge in Copenhagen (at COP 15) in 2010 to achieve an 83% reduction in emissions by 2050 compared to the 2005 level (this would be equivalent to 67% reduction with 1990 as a reference).

None of the declarations concerning 2050 (compiled from various sources including: Citepa-Mark Tuddenham, 2006, UNFCCC, 2010) are considered as legally binding. However, they show that, in an international perspective, most major economies assume a factor 4 or 5 reduction as their long term target.

Rationale for the 2°C target, and linkage with the “factor 4” strategies

Why a 2°C target?

Meinshausen et al. (2009) report that “more than 100 countries have adopted a global warming limit of 2°C or below (relative to pre-industrial levels) as a guiding principle for mitigation efforts to reduce climate change risks, impacts and damages”. What is the rationale for such an objective? In 1988, and based on mounting evidence of the growing atmospheric concentration of greenhouse gases, the World Meteorological Organisation (WMO) and the UN Environmental Programme (UNEP) decided to create the Intergovernmental Panel on Climate Change (IPCC) that aims to assess the role of human activities on climate, their impact and the options for mitigation and adaptation to a possible climate change.

The IPCC has since produced four assessment reports: the first one in 1990 [completed by a supplementary report produced in 1992 for the negotiations of the UN Framework Convention on Climate], the second in 1995, the third in 2001 and the fourth in 2007. A fifth is planned for 2014.

It has been argued by the IPCC [2007] that, as the global mean temperature increases, so will the number and scale of the negative impacts mankind will have to face. It should be noted that some effects will only appear as a warming threshold is crossed. Others, already existing, will worsen and could become unmanageable.

During the course of these IPCC reports, the degree of certainty on the anthropogenic origin of climate change has been reinforced reaching “very likely” in the fourth report, and the cumulative scientific results collected over the period are increasingly converging to the conclusion that strong action will have to be undertaken in the coming decades if adverse and unpredictable effects on the climate (and on the access to resource and food production) are to be avoided.
The scientific evidence summarized in the following figure advocates that long-term concentrations should be stabilized at 450 ppm CO₂ eq in order to retain a 50% probability of remaining below the 2°C increase threshold.

An indicative target for temperature increase of +2°C (compared to pre-industrial average temperature) has indeed been identified as sufficient to avoid too severe impacts. This objective has been acknowledged by the European Union (119) and mentioned in the Copenhagen accord (120).

What does the 2°C objective imply for Annex 1 and Non Annex 1 countries?

Since COP 15 in Copenhagen in December 2009, the political distinction between Annex 1 (mostly industrial countries, among which EU countries) and Non Annex 1 countries – that was so important in the UN-Framework Convention on Climate Change and the Kyoto Protocol – has become more blurred and less fundamental in the negotiation process. However, this classification of countries remains useful at least to try and associate abatement efforts to individual nations.

The IPCC in the 4th Assessment Report also published the highly interesting but equally controversial table below, where it provides ranges of GHG reductions for the two groups of countries for 2020 and 2050 that consistent with the 2°C trajectory. The range of reductions compatible with a 450 ppm CO₂ eq scenario indeed goes beyond factor 4 for Annex 1 countries, assuming a minimum reduction of 80% with respect to 1990 emission levels.

Synthesis of quantitative results of recent low CO₂ studies

A growing number of studies have been launched in recent years to explore long-term low-carbon scenarios. They usually involve different modelling tools to ensure both the consideration of

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See the Communication from the European Commission, Limiting Global Climate Change to 2 degrees Celsius – The way ahead for 2020 and beyond, 10.1.2007.

UNFCCC (2009), Report of the Conference of the Parties on its fifteenth session, held in Copenhagen from 7 to 19 December 2009. The 2nd paragraph of the accord states that “deep cuts in global emissions are required [...] so as to hold the increase in global temperature below 2 degrees Celsius”.

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Figure 2.63: Eventual temperature change depending on GHG concentrations
various complementary analyses (macroeconomic, detailed energy system evolution, land-use,...) and comparison across models for “sensitivity analysis”.

Obviously, there remain major uncertainties about the robustness and relevance of such forward-looking exercises, for several reasons: the link between GHG emissions and climate due to the complexity of the climate system, the modelling of socio-economic organisation and the evolution of the energy system over the very long term, technological breakthroughs and the impact of climate change on the economy. Nevertheless, some recent forward-looking studies have produced insights and preliminary conclusions that merit consideration for long-term policy-making, given the current state of the art in terms of technology description and economy representation.

We propose here a synthesis of three recent studies: the EMF22 on International Scenarios

<table>
<thead>
<tr>
<th>Table 2.6: Burden sharing between Annex I and Non Annex I countries</th>
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<tbody>
<tr>
<td><strong>The range of the difference between emissions in 1990 and emission allowances in 2020/2050 for various GHG concentration levels for Annex 1 and Non-Annex 1 countries as group</strong>^a^</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scenario category</th>
<th>Region</th>
<th>2020</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-450 ppm CO₂-eq</td>
<td>Annex 1</td>
<td>-25% to -40%</td>
<td>-80% to -95%</td>
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<tr>
<td></td>
<td>Non-Annex 1</td>
<td>Substantial deviation</td>
<td>Substantial deviation</td>
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<td></td>
<td></td>
<td>from baseline in Latin</td>
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<td>America, Middle East</td>
<td>regions</td>
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<td>and Centrally-planned</td>
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<td></td>
<td></td>
<td>Asia</td>
<td></td>
</tr>
<tr>
<td>B-550 ppm CO₂-eq</td>
<td>Annex 1</td>
<td>-10% to 30%</td>
<td>-40% to -90%</td>
</tr>
<tr>
<td></td>
<td>Non-Annex 1</td>
<td>Deviation from baseline</td>
<td>Deviation from baseline</td>
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<tr>
<td></td>
<td></td>
<td>in Latin America and</td>
<td>in most regions, espe-</td>
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<td></td>
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<td>Middle East, East Asia</td>
<td>cially in Latin America</td>
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<td></td>
<td></td>
<td></td>
<td>and Middle East</td>
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<tr>
<td>C-650 ppm CO₂-eq</td>
<td>Annex 1</td>
<td>0% to -25%</td>
<td>-30% to -80%</td>
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<tr>
<td></td>
<td>Non-Annex 1</td>
<td>Baseline</td>
<td>Deviation from baseline</td>
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<td>Middle East, East Asia</td>
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</table>

Notes: ~a~ The aggregate range is based on multiple approaches to apportion emissions between regions (contraction and convergence, multistage, triptych and intensity targets, among others). Each approach makes different assumptions about the pathway, specific national efforts and other variables. Additional extreme cases – in which Annex 1 undertakes all reductions, or non-Annex 1 undertakes all reductions – are not included. The ranges presented here do not imply political feasibility, nor do the results reflect cost variances.

~b~ Only the studies aiming at stabilization at 450 ppm CO₂-eq assume a (temporary) overshoot of about 50 ppm (see Den Elzen and Meinshausen, 2006).

[2009], the ADAM project (ADaptation And Mitigation) for the European Commission (2006-2009) – both of which use different international models and provide inter-model comparisons – and a survey for the French foundation FONDDRI on future world low-carbon scenarios.

We present the key results of these studies in terms of energy consumption trends and the carbon intensity of the energy mix, the contribution of various technological and sectoral options to the mitigation effort, and finally the abatement costs (marginal and total).

**Options to radically mitigate GHG emissions**

The following section describes the results of different mitigation options using the POLES model from the ADAM project (2000-2100) and figures from the IEA BLUE Map Scenario (2000-2050) from the Energy Technology Perspectives 2008 (IEA 2008).

Although conducted with different tools, methods and without any coordination or attempted convergence, the results show striking similarities, as shown on the following graphs. The differences are mostly due to the different levels of emission constraints (world emissions 2050 reach 14 GtCO₂ in the BLUE Map versus 6.3 GtCO₂ in POLES-ADAM400).

Firstly, efficiency in final energy consumption appears to be key to emission reductions: 35% in POLES-ADAM and 36% in the BLUE scenario (12% for electricity and 24% for other fuels). This leads to a stabilisation of energy consumption from 2020 onwards, a fairly ambitious prospect, given the expected population growth and growth of energy needs in line with the increasing income per capita, be it for transport needs, heating & cooling or access to communication technologies.
New energy supply and transformation technologies are to play potentially very important roles: CCS could represent around 20-25% (which is remarkable for a technology which does not exist yet beyond specialised small-scale applications in oil fields), and large scale renewables a portion of the power mix ranging from 15% (in 2050 for the BLUE Scenario) to 25% (by 2100 in ADAM400, with more constraints on CO₂ reductions, including a substantial contribution in the second half of the century).

The fuel switch in final demand towards a more carbon-neutral mix arrives fourth with 10% in ADAM400 (electrification, direct use of biomass, solar heating, other fuel switching) and 11% in the IEA BLUE scenario (electrification, end use fuel switching, FCVs).

[121] We will not comment here on the numerous uncertainties related to future nuclear technologies and the organization of nuclear fuel markets. The POLES model uses technico-economic description of generic technologies from the TECHPOL database built by the LEPII-CNRS. Work is underway between LEPII-CNRS and LPSC-CNRS (Grenoble, France) to investigate more thoroughly the evolution of nuclear industry over the long term and the contribution of various technological options.
Finally nuclear contributes “only” around 5% of the total abatement effort, which is mostly related to its substantial development in Baseline scenarios: its contribution in the global energy mix increases from 6.5% in 2005 to 8% in 2050 and 11.6%, including contribution from fast breeders[121].

The contribution of a fossil fuel switch in the power sector (from coal to gas) soon becomes marginal in POLES compared to the penetration of CCS associated with coal and gas plants and the development of alternative technologies, notably renewables, but it remains an important option in the IEA BLUE scenario in 2050 (7% of total reductions).

The results stress the importance of some emission reduction options:
- reduction of final energy demand, in a context of growing population and income;
- development of an (almost) entirely new technology: the capture and sequestration of carbon;
- large scale development of renewables, and in particular of biomass use.

Each of these options raises distinct challenges and issues.

**Energy efficiency**
As underlined previously, a substantial share of the effort should be achieved through a decline in energy demand. These gains will depend on a variety of energy efficiency strategies: the uptake of more efficient technologies, a change in behaviour and a limitation of the “rebound effect” brought about by potentially decreasing the budget allocated to energy consumption as a result of the availability of more efficient technologies. Policies will have to combine the entire toolkit of energy-efficiency strategies: adopting standards for equipment and for buildings insulation, supporting innovation and incentives to adopt efficient technologies, setting appropriate price signals on energy use to direct investment decisions and behaviour towards more rational energy use, information campaigns to raise public awareness and reduce the political cost of future constraining measures. There will need to be efforts on both the technological and the lifestyle front, all the more so as they usually feed off each other.

**CCS**
Remarkably, the results of long-term low CO₂ profiles all show a major contribution of the deployment of CCS technology. This is an
important result, with considerable political and technological implications. Indeed, although used in the oil industry to improve the recovery rate in oil fields, CCS is still a long way from deployment at the scale projected in these scenarios (4,600 GW by the end of the century in ADAM400, roughly the entire current power generation capacity): capture efficiency, transport of liquefied carbon and localisation of future plants (areas consuming electricity vs. localisation of storage capacities), cost of the overall chain (capture, transport, storage, monitoring), and most importantly the availability and long-term viability of the storage capacity.

There is an important role to be played by policymakers in creating an environment favourable to the long-term development of this technology: strong support to R&D costs and pilot projects, identification of suitable storage sites, long-term foreseeable constraints on CO₂ emissions to secure investment decisions.

Scenarios without any CCS have also been explored, but their key results are not presented.

**Renewables**

As with CCS, the scenarios also rely strongly on the large scale development of renewables. This forecasted development integrates technical and resource limitations to the extent to which the modelling manages to capture them properly, in other words not always with the desirable level of detail, and usually relying on conditions that may be too restrictive as regards the development of future technology [full “smart grids” integrating intermittent resources and storage capacities in electric vehicles for example].

In particular, the issue of intermittency and its impact on future network management and investment decisions for “conventional” capacities (thermal, nuclear) appear crucial for wind and solar development. The large-scale use of biomass may lead to problems of land use, and may be a source of local pollution [122], although some studies argue that biomass use could actually reduce local pollutant emissions [123]. In addition, the assumption on its neutrality as concerns CO₂ emission could be challenged.

The impact on land use is dealt with in detail for Europe in the section 2.2.2 above.

**Climate policies and future energy markets**

One important outcome of the scenarios is the impact on future fossil fuel markets of GHG-related policies.

Without pretending to predict the exact level of oil price over the long term, the POLES model is useful in forecasting possible “fundamental price” evolutions, to be understood as a proxy of the level of tension between demand and supply on the future oil market. It is remarkable that such levels are actually significantly impacted by CO₂ reduction measures. This effect becomes significant only after 2020, in line with the high viscosity (low elasticity) of the largest oil consuming sector, transport, to CO₂ price signals, and the subsequent slow pace of change [efficiency, alternative technology development, ...].

However, from 2030 there are clear differences, with increasing social tension in the Baseline case [even though this scenario is based on a fairly optimistic estimates of recoverable resources over the long term – see Kitous et al, 2010] compared with moderate increases in oil price in the ADAM550 and ADAM450 cases, and a disappearing oil consumption in the 400ppmv scenario that lead to very low oil prices [and thus to very low levels of tension on the oil market].

The peaks in conventional oil production can be related to a problem of supply in the Baseline case, leading to rising prices, while in the constrained scenario the peak is demand-related, triggered by the carbon value.

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Coal use is immediately negatively impacted by the introduction of carbon price, stabilises around 3 Gtoe by 2030 (6 Gtoe in the Baseline) before declining afterwards to less than 1 Gtoe by the end of the century (14.5 Gtoe in the Baseline). These levels of consumption are also linked to CCS: 20% of gas use and 65% of coal use by 2030, respectively 50% and 87% by 2050.

Similarly, the strong climate policies lead to lower consumption, and thus “easier” markets for gas and coal over the long-term, compared with a Baseline case.

In the case of gas, consumption is positively impacted by climate policies by 2025 (in addition to the growth in the Baseline situation), where it peaks at 3 Gtoe before declining in line with increasing constraints on CO₂ emissions to 2.2 Gtoe in 2050 (3.4 Gtoe in the Baseline) and less than 2 Gtoe by the end of the century. Coal use is immediately negatively impacted by the introduction of carbon price, stabilises around 3 Gtoe by 2030 (6 Gtoe in the Baseline) before declining afterwards to less than 1 Gtoe by the end of the century (14.5 Gtoe in the Baseline). These levels of consumption are also linked to CCS: 20% of gas use and 65% of coal use by 2030, respectively 50% and 87% by 2050.

The dramatic shifts in lifestyle and development patterns required for a transition to a low-carbon economy call for an extremely ambitious policy approach, in both scope and coverage. Designing the details of this approach will require particular care, considering what is at stake: long-term studies hint that the cost of deviating from the lowest-cost option – whatever this might be – could be in the order of several GDP points in 2050 for the most ambitious targets, a measure that translates into hundreds of billions of Euros in Europe. From the available literature on the topic there emerges a set of generic principles that, theoretically guaranteeing cost minimisation, should at least hedge against massive extra costs.
First and foremost, coordination in the policy process is a requisite to efficient action. In economic terms, the primary aim of such coordination is to guarantee ‘when flexibility’ to abatement measures: considering that the impact of emissions on the climate is independent of their geographical origin, they should be cut where it is the cheapest to cut them. This rationale is certainly relevant at the European level, where recent governmental reports and studies insist on the need for a strengthened integrated approach. It also holds at the global level, although the recent semi-failure of the Copenhagen summit, and the monitoring difficulties inherent in Clean Development Mechanism (CDM) actions, postpone to some unknown future the equalisation of marginal abatement cost across the globe. The following sections will focus on European policymaking and avoid opening the debate on the contribution of non-European offsets.

The same series of governmental reports, drawing conclusions from a profuse scientific literature, stresses the importance of timing: even accounting for the slack given by the ongoing global economic crisis, delayed action closes one-by-one the windows of opportunity to reach lower concentration levels, while increasing the costs of meeting those that can still be met. Policy action is needed, at the very least, to set the European economy on track such that its laker 2050 target of a 60% emission cut from 1990 levels could still be attainable. In a similar line of thought, there are fears that the -20% 2020 objective might be too conservative a milestone on route to this ambitious 2050 target. Considering the political process that led to the adoption of these targets, it is hard to rule out that another emission pathway might induce the same environmental benefits at a lower economic cost.

A third generic recommendation of most studies and reports is that the distributive consequences of ambitious climate policies should be duly assessed, and controlled as far as possible: on households, to shield the poor from strong direct impacts on their living standards; on firms, to prevent unilateral action undermining their competitiveness on international markets; on governments, to guarantee that climate policies neither deteriorate (through subsidies and tax cuts) nor improve (through tax and auction proceeds) public budget balances.

Finally, many studies underline the need for education: to gain public acceptance the policy portfolio will have to be straightforward. At the level of constraints envisaged, overly complicated schemes would probably fail to achieve buy-in. This, together with its theoretical properties, would seem to recommend some generalised form of carbon pricing as the core of any policy action – a first subsection will address this central instrument. However, further targeted policy measures will also be required, to tackle a number of market failures and imperfections that could be addressed at moderate technical cost. A second section will detail the wide range of such instruments promoted in the policy-oriented literature.

Energy supply
The stress on energy supply is put first and foremost on the production of electric power, and the need for a much higher rate of renewables to meet ambitious concentration targets. The main barrier to the development of renewable energies is identified by all studies, explicitly or implicitly [considering their policy recommendations], as

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[126] Although the corresponding principle of “budget neutrality” offers some leeway in its practical implementation.
the historical consequence of state-funded, planned, massively subsidised, power production.

To overcome the implied barriers the first obvious move identified by most studies is to create a “level playing field” (BMU, 2008; Greenpeace, 2005) by ending subsidies to conventional electricity production; Greenpeace quotes OECD figures of an estimated $250-300 billion each year in subsidies worldwide (Greenpeace, 2005), which distort markets in favour of fossil- and nuclear-based electricity. Policy action should lift existing subsidies rather than align subsidies for renewables with existing support for conventional power production: it is essential to energy efficiency improvements that the real cost of electricity should be passed through to consumers which also requires an end to regulated prices, as CAS (2008) advocates in the case of France. On top of this obvious move, some studies insist on the need to level the field between the renewable options themselves (and more broadly to align the incentives created by the wide array of energy policies that are currently in force): existing incentives should be thoroughly reviewed, and made consistent (BMU, 2008). The analyses by CAS (2009) and DECC (2009) of the existing support instruments in respectively France and the United Kingdom reveal indeed large discrepancies in the implicit ‘private’ value of carbon. This should be taken as a hint that the social values, which we have seen do not necessarily correspond to the private ones, are also mismatched.

But for most studies creating a level playing field is just a prerequisite, and will not be enough to overcome the consequences of decades of public support, firmly anchored in existing technologies and infrastructure. This makes the case for a series of complementary policies and measures as:

- feed-in tariffs, extensively supported (Greenpeace, 2005, 2008; ZCB, 2007; BMU, 2008, which more specifically supports the German Renewable Energy Sources Act of 2000 and its 2004 amendment). To reduce uncertainty and avoid inefficient “stop-and-go” markets, these should be guaranteed to a mid-term horizon – Greenpeace (2005) stipulates a 20-year horizon. BMU (2008) however stresses that the tariffs can be gradually phased out, starting as early as 2015 in the German case, as the combined forces of productivity gains from market developments and steady increases in fossil fuel prices make them economically viable. In 2023 the portfolio of renewables projected by BMU is self-financing, at least from an aggregate perspective. A similar general argument is found in Negawatt (2006);
- legally binding renewable targets (Greenpeace, 2005; CCC, 2008). As an extension and strengthening of the Renewables Directive of 2001, the share of renewables in electricity production should be imposed for further time horizons to form a “renewable share pathway”;
- simplification and acceleration of the administrative procedures surrounding electricity production and access to the grid (Greenpeace, 2005; BMU, 2008, CCC, 2008). Administrative barriers should be removed at all levels and a “one-stop-shop” system, complemented by clear timetables for project development, should be introduced (Greenpeace, 2005; BMU, 2008). On the particular question of the grid, this requires due transposition of existing European legislation by Member States, among others regarding an effective unbundling of historical utilities into separate generation and distribution companies. A grid authority should guarantee similar, transparent conditions to all producers, and bear the costs of infrastructure development rather than bill it to renewable energy projects.

[127] Cf. OECD [1998], Improving the Environment through Reducing Subsidies, OECD Publishing, Paris. Greenpeace also quotes a Worldwatch Institute estimate that total world coal subsidies are $63 billion, while in Germany alone the total is €21 billion, including direct support of more than €85,000 per miner.

[128] This is notwithstanding the benefits from building industrial export capacity, underlined, if not assessed, by BMU (Lead Study 2008: Further development of the “Strategy to increase the use of renewable energies” within the context of the current climate protection goals of Germany and Europe, Nitsch, J. [ed.], German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU)).

[129] The costs of the still substantially more expensive solar photovoltaic technology being compensated by the competitiveness of all other renewable technologies envisaged. BMU advocates that solar photovoltaic is to be supported, despite a considerable mark-up in current market conditions, to create the conditions for it to take up a large market share from 2030 on.
Some studies insist on the fact that both the renewable targets and the feed-in tariffs should be expressed in a way that preserves technological diversity, which should play a crucial role in attaining the most ambitious targets (Greenpeace, 2005). This obviously constitutes quite a challenge for tariffs, as it implies a thorough prospective on the future relative costs of the renewable technologies.

The targeted increase in renewable energy supply calls for improvements to the electric grid in the fields of storage, transport and distribution. Electric grids are to be upgraded to “smart grids” to allow power production to be balanced by decentralised and intermittent units (ZCB, 2007; CAS, 2008, specifically targeting electric heating). Greenpeace (2005) thus advocates that the level and timing of demand for electricity could be managed by providing consumers with financial incentives to reduce or shut off their supply at periods of peak consumption – a technical solution also envisaged by CAS (2008). Furthermore ZCB suggests variable electricity pricing; consumers should be given the choice between uninterruptable, expensive contracts, and discounted rates where energy companies can control appliance use to balance demand; they should be allowed to sell the use of their onboard power and battery storage back to utility companies while these are not being used – a most innovative “vehicle to grid (V2G)” system is promoted.

Still, BMU (2008) supports the German CHP Act (in its latest amended version), particularly for the promotion of the modernisation of existing CHP plants alongside the building of new ones, as well as the crucial expansion and creation of heat grids. It however questions the level of support to heat providers based on two German studies. It also promotes the German Renewable Energies Heat Act of 2007 and the corresponding act in Baden-Württemberg as preliminary measures, at least, that should be speedily extended to all types of building (the national act is restricted to new buildings, while the regional one includes them but covers residential buildings only), while the mandatory use of renewables should be extended to the building stock. Finally it stresses the role that local authorities will have to play to accelerate structural change in grid-connected heat supply.

To conclude this section on energy supply, it is worth mentioning that none of the surveyed studies place a strong emphasis on biofuels.
The general stance is rather one of cautious support, considering both the uncertainties regarding the lifecycle assessment of that energy carrier (CAS, 2008), especially when imported from outside the EU (BMU, 2008), and the potential undesired side-effects on food prices prompted by the competition with food production in the use of land (BMU, 2008). Nonetheless BMU (2008) identifies tax exemptions for biofuels, and the German Biofuel Quota Act of 2006, as highly effective measures that have allowed the share of biofuels to rise steeply in the German context.

**Energy demand**

The “efficiency gap” in energy demand must be fully tapped to reach the ambitious 2050 objective of a 60%-80% cut in GHG emissions compared to 1990. Greenpeace (2008) estimates that current European energy demand can be cut by as much as 30% in a cost-effective manner. Going even further, by thoroughly rethinking energy services from scratch, rather than working with current constraints, could allow efficiencies in the order of a factor four to ten (Greenpeace, 2008). ZCB (2007) and Negawatt (2006) also insist on the necessity of energy savings as a third major component of a transition to a low-carbon society.

Mandatory energy efficiency targets could pave the way to this objective (Greenpeace, 2005): Greenpeace criticises the low mandatory European targets for annual energy savings, which equal just 1% of private customer energy use and 1.5% of the amount distributed to the public sector, and advocates annual targets of at least 2.5% for the private sector and 3% for the public sector.

More specific measures detailed by the various reports are in line with the main contributors to energy savings they envisage. Buildings and transport receive the main focus, while appliances and end-use equipment are also targeted. Industry, however, is consistently viewed as sensitive enough to market signals to restrict the policy measures targeting it to carbon pricing.

**Buildings**

Buildings are stressed by many studies as one if not the major source of potential energy savings, and indeed one that cannot be left untapped if ambitious targets are to be met (ZCB, 2007; CAS, 2008; Radanne, 2004). A strong emphasis is placed on the slow dynamics of building stocks (ZCB, 2007; crucial to Radanne, 2004 – one of his “interdits” i.e. cannot do without; CAS, 2008). CAS also stresses the highly decentralised nature of decision-making in the building sector, and the financial constraints weighing on many of its actors – ZCB insists on the latter as well, and advocates that some of the proceeds of the quota auction it promotes be used to finance investment by poorer households.[130] This makes the case for a vast, strong, coordinated and continued public action.

General recommendations include a strengthened and accelerated development of building regulations for new construction (Radanne, 2004; ZCB, 2007; CAS, 2008; Greenpeace, 2005 and 2008; INFORSE, 2008; BMU, 2008). INFORSE (2008) more specifically proposes to raise mandatory building codes so match current low-energy housing levels as early as 2010, and to require that all major renovation include a major energy renovation – but does not detail how this should be enforced. As regards energy efficiency, suggests that passive houses be the subject of a massive R&D programme, and once developed become the basis of updated energy standards. CAS (2008) proposes that any new building should be obliged to incorporate heat pumps, renewable heating or solar thermal hot water. Greenpeace (2008) recommends a similar mandatory share of renewable sources to heating and cooling, while CCC (2008) calls for an appropriate framework to support the wide-scale deployment of renewable heat. A couple of studies insist on the need to monitor these constraints and liabilities (ZCB, 2007; CAS, 2008), based on surveys revealing the “implementation gap” between regulations and actual performances.

[130] Although it is specifically pregnant in the building sector where investment costs are high, limited investment capacity also impacts end-use equipments.
The existing stock should also be subjected to an ambitious refurbishment programme (BMU, 2008; Negawatt, 2006), with a view to speed up convergence between the efficiency of existing stock and that of new constructions (Radanne, 2004). One way to implement this convergence is suggested by ZCB (2007), which proposes “mandatory energy efficiency improvement at exchange of contract on sale, and when letting”. Less targeted measures include tax rebates in exchange for installing efficiency measures, and a VAT exemption for refurbishment expenses. ZCB expresses support for the British Warm Front programme (grant programme directed to poorer households) and the Decent Homes programme (refurbishment of social housing). CAS (2008) and CCC (2008) voice support for the certificates mandated by the EU directive on the energy performance of buildings, as they concretise the constraint on real estate markets. Among other provisions based on energy performance certificates (EPCs), CAS (2008) proposes that:

- firms could be required to publish an indicator of the energy performance of the buildings they own or occupy;
- landowners could be forbidden to increase the rents of properties that belong to the lowest categories of energy performance certificate (EPC);
- an accelerated amortisation of the purchase or refurbishment costs of a building could be allowed if the building belongs to higher EPC categories.

CAS also develops a collection of measures specific to the French economy (extension to landlords of the tax credits earned by energy savings and renewables investments, effective implementation of the obligation of individual accounting for collective heating systems, suppression of the reduced VAT rate on cooling systems). Alternatively, ZCB (2007) supports a transition of energy companies to energy service companies, which charge for the provision of energy services (lighting, warmth, hot water, etc.) rather than energy units, with the advantage of trusting to such specialised companies the complex optimisation problems of energy systems. The shift to such market organisation has been tentatively started by the Supplier Obligation in the UK, which is strongly supported by CCC (2008).

**Transport**

The second main energy demand sector identified for specific policies and measures is transport, for the obvious reasons of its continued growth and reliance on fossil fuels (CAS, 2008).

A first series of recommendations concern a “systemic approach” to the transport problem: it is only through a concerted reform of a broad range of public policies related to urban planning, land settlement, business supply chain organisation, and so on, that the growth in transport emissions can be contained (Radanne, 2004; Negawatt, 2006; CAS 2008b, although cautiously subordinating such changes to public acceptance). Radanne (2004) urges early action, considering the dynamics of public intervention. ZCB (2007) advocates some infrastructure changes in the sense of improved cycle lanes (also supported by Greenpeace, 2005) and pedestrian facilities to help reduce vehicle usage and encourage alternative modes of transport. The need for specific instruments to foster teleworking and car-sharing is underlined by Negawatt (2006) or CAS (2008), although these instruments are not pinpointed. CAS stresses the need to lift legal obstacles that hamper car-sharing (insurance, expenses eligibility), while Greenpeace (2005) points to Japan as a “best practice” country for passenger transport, considering the large share of rail in total passenger kilometres it exhibits (29% in 2004), thanks to a strong urban and regional rail system; and Canada for freight transport, but without detailing specific policy measures.

The reports advise more targeted measures for **passenger cars**. Greenpeace (2008) advocates strict technical standards, together with measures to guarantee that vehicle size decreases. CAS (2008) pinpoints an objective of 120g/km in 2012 for new personal cars – 10g/km stricter than the EU objective, and CCC (2008) one of 100 g/km in 2020;
both studies agree that standards should be imposed on all other classes of motor vehicle as well. CAS [2008] also suggests that existing efficiency-improving equipment could be made mandatory (instant fuel consumption display, tyre pressure gauge, cruise control, etc.). To downsize vehicles, Radanne [2004] supports a bonus/malus [reward/penalty] scheme akin to the one introduced in France in 2008,[13] highlighting it as a good way to use taxation to shape consumer behaviour rather than raise tax revenues. CCC [2008] supports a similar incentive, although in less precise terms. Radanne also suggests a mandatory tie-down of engines at a European level, stating that this could reduce fuel consumption by 20% – but without addressing the problem of different speed limits in Member States. CAS [2008] does, and advocates that a harmonised upper limit of 130 km/h should be enforced, not so much for its direct impact on fuel consumption, as for its indirect impact on the power of cars, which would allow for reduced consumption in all driving cycles alike. CAS also stresses the role that training drivers in ‘eco-driving’ and information campaigns could play, advocates the development of urban tolls, but also of time-dependent toll pricing [implying reduced fuel waste through congestion], and suggests that a vignette should be reintroduced on a CO₂ emission basis, based on a €100 carbon value and on an average 14 000 km per year. CCC [2008] also mentions the potential impact of a CO₂-based vignette, without pinpointing levels.

Targeted measures on other transport modes are few. On road freight, CAS [2008] recommends a kilometre-fee that could be enforced thanks to GPS data. Negawatt advocates a specific taxation of low-cost air transport, without more precision. ZCB, in line with its extreme scenario of a 20-year carbon phase-out for UK, goes as far as suggesting that the nationalisation of coach and rail services could be required to meet its ambitious objective of a fourfold development of rail and coach transport. Simultaneously, it advocates that the rail network should be entirely electrified (one-third remaining to be done in the UK).

Appliances
A third series of measures addresses appliances and end-use equipment, whose contribution to residential energy consumption has increased consistently in recent decades. Recommendations include:

- in line with the 2005 EUP Directive, an extension of environmental labelling to provide more product information [Greenpeace, 2008; CAS, 2008; ZCB, 2007; CCC, 2008]. ZCB further specifies that energy ratings should be permanent and clearly visible, to play on reputation effects; and should be split in two to reflect active and standby power consumption, considering the growing number of equipment with permanent plug-in requirements;
- on top of labelling, strict technical standards are advocated [Radanne, 2004; Greenpeace, 2008; CAS 2008b] to guarantee that the least efficient appliances are denied access to market. Radanne (2004) underlines that this should help cut the cost of more efficient appliances by guaranteeing them larger markets. CAS (2008) specifically mentions the case of light bulbs.

[13] The buyer of a new car is subject to a range of taxes or subsidies depending on the car’s average CO₂ emissions per kilometre.
Policies and measures beyond the energy markets

Most studies promote a set of further measures to target energy demand and supply. A first field of policy intervention, still strongly connected with the energy markets, is R&D support. The need for a strong, coordinated and immediate R&D effort is consistently stressed, to foster technical change in both energy-producing technologies and end-use equipment. Radanne (2004) addresses timing, stressing that standard 2050 technologies must have hit market competitiveness around 2030, which means that they must reach the stage of prototypes by 2020, and should thus proceed from programmes launched in the very few years to come. Some studies place the stress on particular fields of research, that can be split in two:

- specific end-uses and end-use equipments: cooling (Greenpeace, 2008); private cars (Radanne, 2004); positive energy buildings (CAS, 2008);
- ancillary technologies: heat storage (Greenpeace, 2008), electricity storage, transport and distribution (ZCB, 2007; CAS, 2008); carbon sequestration (Radanne, 2004; CAS, 2008, with mention of the potential global market to seize; CCC, 2008), although some studies exclude this as an unsustainable option (ZCB, 2007; BMU, 2008).

Although most if not all studies advocate support for renewable technologies, CAS (2008) is the only one to identify a priority, namely second generation biomass, stressing that support cannot be generalised if it has to be efficient, considering the current state of public budgets (132). On the contrary ZCB (2007) stresses that R&D programmes should strive to balance their support to competing technologies and let the market elect the most efficient.

A second policy recommendation regards public awareness campaigns. Such campaigns are advocated by many reports, either on loose terms (“energy efficiency”), or on more specific issues, including driving behaviour, heating and cooling practices, and standby power consumption. In a similar line of thought, demonstration projects are advocated on the particular questions of building efficiency by Greenpeace (2008), and on the CCS technology, by CCC (2008).

A third and last field of policy intervention regards the implementation of ambitious training programmes, that would be required on many job markets to meet the escalating demand due to low-carbon policies. First and foremost of these markets is construction, in a broad rather than a narrow sense, i.e. from building conception to consultancy on energy performance to refurbishment and construction proper (CAS, 2008; Greenpeace, 2008; ZCB, 2007). Again, some stress is placed on timing, considering the time required to organise and develop the appropriate training courses (CAS, 2008).

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(132) CAS also advocates strong public support to 4th generation nuclear and nuclear waste treatment. We have deliberately left out the nuclear phase-out question, which is clear cut in the NGO reports, and strictly echoing national agendas for the French and German public reports.
**List of acronyms**

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>ADAM</td>
<td>ADaptation And Mitigation</td>
</tr>
<tr>
<td>ADEME</td>
<td>Agence de l’Environnement et de la Maîtrise de l’Énergie</td>
</tr>
<tr>
<td>ASEAN</td>
<td>Association of South-East Asian Nations</td>
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<tr>
<td>BEV</td>
<td>Battery Electric Vehicle</td>
</tr>
<tr>
<td>BMU</td>
<td>Bundesministeriums für Umwelt</td>
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<tr>
<td>BTL</td>
<td>Biomass-to-liquids</td>
</tr>
<tr>
<td>CAS</td>
<td>Centre d’Analyse Stratégique</td>
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<tr>
<td>CCC</td>
<td>Committee on Climate Change</td>
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<td>CCS</td>
<td>Carbon capture and storage</td>
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<tr>
<td>CDM</td>
<td>Clean Development Mechanisms</td>
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<tr>
<td>CGP</td>
<td>Commissariat Général du Plan</td>
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<tr>
<td>CIS</td>
<td>Community of Independent States</td>
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<tr>
<td>CO₂</td>
<td>Carbon dioxide</td>
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<td>CTL</td>
<td>Coal-to-liquid</td>
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<tr>
<td>DECC</td>
<td>Department of Energy and Climate Change</td>
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<td>DEFRA</td>
<td>Department for Environment, Food and Rural Affairs</td>
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<td>EDI</td>
<td>Economic Development Index</td>
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<tr>
<td>EEA</td>
<td>European Environment Agency</td>
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<td>EMF</td>
<td>Energy Modelling Forum</td>
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<td>EPC</td>
<td>Energy Performance Certificate</td>
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<td>ESI</td>
<td>Energy Service Index</td>
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<tr>
<td>ETS</td>
<td>Emissions Trading System</td>
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<tr>
<td>EU, EU25, EU27</td>
<td>European Union, 25 EU countries, 25 + 2 accession countries</td>
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<tr>
<td>FAO</td>
<td>Food and Agriculture Organisation</td>
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<tr>
<td>FCV</td>
<td>Fuel Cell vehicle</td>
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<td>GDP</td>
<td>Gross Domestic Product</td>
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<tr>
<td>GHG</td>
<td>Greenhouse Gas</td>
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<tr>
<td>GJ</td>
<td>Billion Joules</td>
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<tr>
<td>Gm³</td>
<td>Billion Normal cubic meters</td>
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<tr>
<td>GPS</td>
<td>Global Positioning System</td>
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<tr>
<td>Gt</td>
<td>Billion tons</td>
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<tr>
<td>Gtoe</td>
<td>Billions of tons oil equivalent</td>
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<td>h</td>
<td>hour</td>
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<tr>
<td>ICE</td>
<td>Internal Combustion Engine</td>
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<tr>
<td>ICTs</td>
<td>Information and Communication Technologies</td>
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<tr>
<td>Abbreviation</td>
<td>Full Form</td>
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<tr>
<td>IEA</td>
<td>International Energy Agency</td>
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<td>IFP</td>
<td>Institut Français du Pétrole</td>
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<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
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<tr>
<td>H₂</td>
<td>Hydrogen</td>
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<tr>
<td>LNG</td>
<td>Liquefied Natural Gas</td>
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<tr>
<td>Mbd</td>
<td>Million barrels per day</td>
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<tr>
<td>MJ</td>
<td>Million Joules</td>
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<tr>
<td>Mt</td>
<td>Million tons</td>
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<tr>
<td>NGO</td>
<td>Non Governmental Organisation</td>
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<tr>
<td>OECD</td>
<td>Organisation for Economic Cooperation and Development</td>
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<tr>
<td>OPEC</td>
<td>Organisation of Petroleum Exporting Countries</td>
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<tr>
<td>PACT</td>
<td>Pathways for Carbon Transition</td>
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<tr>
<td>PKM</td>
<td>Passenger-km</td>
</tr>
<tr>
<td>PJ/a</td>
<td>PetaJoules [1015 Joules] per annum</td>
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<tr>
<td>ppmv</td>
<td>parts per million by volume</td>
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<tr>
<td>ppp</td>
<td>purchasing power parities</td>
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<tr>
<td>PREDIT</td>
<td>Programme de Recherche et d’Innovation dans les Transports Terrestres</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>Research and Development</td>
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<tr>
<td>Tkm</td>
<td>Ton-km</td>
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<tr>
<td>TWh</td>
<td>Billion kWh</td>
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<tr>
<td>UN</td>
<td>United Nations</td>
</tr>
<tr>
<td>UNFCCC</td>
<td>United Nations Framework Convention on Climate Change</td>
</tr>
<tr>
<td>VLEEM</td>
<td>Very Long Term Energy Environment Model</td>
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<td>ZCB</td>
<td>Zero Carbon Britain</td>
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