1. Introduction

The concept of sustainable development has evolved into a guiding principle for a liveable future world in which human needs are met without compromising the ability of future generations to meet their own needs (UN, 1987). One of the implications of the pursuit of sustainable development is that the natural systems that support present and future needs must be maintained. However, addressing the challenge of sustainability encompasses other social, economic and environmental dimensions, and requires a long-term systematic perspective and the integration of many different elements. Energy and transport are two such elements, and directing the global energy system and transport systems onto a sustainable path is becoming an increasingly important concern and policy objective (Schrattenholzer et al., 2004; IEA, 2001; Riahi et al., 2001; Barreto et al., 2003).

Among other factors, climate change constitutes one of the most serious threats to achieving the goals of sustainable development, and for energy sustainability in the long term. There is mounting evidence of human interference with the Earth’s climate system and increasing concern about possible serious adverse impacts resulting from future global climate change (IPCC, 2001a). Realizing sustainable energy and transport systems with a low impact on the global climate, but that still achieve other long-term development goals, such as poverty alleviation and maintaining a secure energy supply, may require profound and wide-reaching changes.

The objective of this book is to analyse these changes in terms of the potential to establish a sustainable global transport system as part of the realization of a sustainable global energy system. Envisioning and understanding how long-term future global energy and transport systems can meet increasingly stringent requirements in a sustainable way is an important element for designing policy responses that will promote the transition towards a future in which economic development, energy security and climate change mitigation are simultaneously realized. However, there are significant social, economic, environmental, technological and political uncertainties that may influence energy system development, meaning that many alternative sustainable energy pathways may emerge.

Accordingly, we examine the technologies and energy carriers that could play a role in these pathways to sustainable development, including their potential, market opportunities and the barriers they could face as well as
the conditions and policy actions necessary for their successful diffusion (Williams et al., 2000). Since the evolution of transport and energy systems is slow and may span decades or sometimes even centuries, the emergence of a sustainable global energy and transport system is likely to be a gradual long-term process requiring profound transformations from the current infrastructure to new systems and structures. This highlights the need to take a very long-term perspective both in terms of studying the potential to realize a sustainable transport system and also when formulating policy responses aimed at securing the benefits of sustainable development.

In this book we seek to take such a long-term perspective and investigate how a possible transition to a transport and energy system compatible with the broader goals of sustainable development could unfold, with the aim of identifying potential technology targets for government policy support and intervention. Importantly, energy and transport systems are faced with unique and substantial challenges in realizing the goals of sustainable development, particularly in terms of avoiding serious consequences of climate change and reducing greenhouse gas emissions. The enormity of this challenge is best illustrated by looking at historical and current trends.

1.1 CLIMATE CHANGE AND SUSTAINABLE DEVELOPMENT

Emissions of greenhouse gases from human activities are leading to changes in the composition of the global atmosphere. This is illustrated in Figure 1.1 for emissions of carbon dioxide (CO₂) – one of the most important greenhouse gases – from combustion of fossil fuels,¹ which have been increasing almost continuously since the industrial revolution. The changes in atmospheric composition from these and other emissions are already leading to changes in climate (IPCC, 2001a) and, depending on future emissions and other uncertain factors, may result in significant changes to global climate (for an illustration of the range of possible impacts on temperature, see Figure 1.2). This is likely to result in a range of impacts on many physical, biological and ultimately human systems, including agricultural productivity, health, biodiversity, precipitation, and flood risk, to name but a few (see IPCC, 2001a, for a more comprehensive description of possible impacts). The impact of climate change on these systems will be wide-scale, long-term and in many cases irreversible, with the possibility of very dramatic and unpredictable changes (ibid.). Anthropogenic climate change affects many of the systems upon which human welfare depends and this represents one of the most serious challenges to achieving sustainable development.
Figure 1.1 Historical atmospheric CO$_2$ concentrations and emissions from fossil fuel combustion

Figure 1.2 Range of future temperature scenarios from IPCC, relative to 1990

The historical increase in emissions of greenhouse gases (GHGs) is the result of a number of demographic, economic, technological, resource and policy driving forces. This can be understood by decomposing emissions into some of the key variables representing these forces, based on the IPAT identity (where Impact = Population × Affluence × Technology) (Ehrlich and Holdren, 1971). For instance, carbon dioxide (CO$_2$) emissions from energy use can be represented by the following decomposition formula:

\[
CO_2 = \text{Pop} \cdot \frac{GDP}{\text{Pop}} \cdot \frac{\text{Energy}}{\text{GDP}} \cdot \frac{\text{CO}_2}{\text{Energy}}.
\]  

(1.1)

Here, the impact on CO$_2$ emissions is a function of population (Pop), per capita incomes (or affluence) (GDP/Pop), and two factors representing technology: the amount of energy required to produce a unit of GDP (Energy/GDP), which depends on economic structure and end-use and conversion technologies, and the carbon intensity of the energy source (CO$_2$/Energy), which depends largely on energy production technology and fuel choice. All other things being equal, an increase in population or affluence will lead to an increase in emissions. Of course, the relationship presented in the decomposition equation is highly aggregated and one needs to remember that changes in consumption and production structure are likely to accompany changes in incomes (Hamilton and Turton, 2002), among others. However, it provides a useful guide to the core driving forces. One additional and critical driving force is policy, which influences all of the elements in the IPAT formula. Accordingly, policy can play a potentially major role in curtailing greenhouse gas emissions.

Looking at historical data, it is clear that the growth in greenhouse gas emissions has usually accompanied economic development and expansion (that is, the combined impact of population and per capita income growth), and Figure 1.3 shows how emissions and global GDP have developed since the early 1970s. However, Figure 1.3 also partly illustrates a slow ‘decoupling’ of economic growth and greenhouse gas emissions, with the global economy in 2000 being roughly 35–40 per cent less carbon-intensive than in the early 1970s, largely as a result of technological development and a shift from emissions-intensive manufacturing to less emissions-intensive services (that is, changes in the technology elements in equation (1.1) above). This development offers some hope for achieving the goals of sustainability, and highlights the potentially important role of technology. Nevertheless, Figure 1.3 also implies that a continuation of historical trends alone is unlikely to be compatible with realizing the goals of sustainable development.

Figure 1.3 partly shows how developed countries (OECD$^2$ and economies in transition (EITs)) have historically been responsible for most emissions of
Introduction


Figure 1.3 Global CO₂ emissions from energy, 1971–2000


Figure 1.4 Per capita emissions, per capita income and population, 2000
CO₂, and developing regions (ROW) are only just now beginning to achieve comparable aggregate emissions (while their per capita emissions remain much lower). Looking more closely at the contribution of different world regions, Figure 1.4 plots regional per capita income against per capita CO₂ emissions from fossil fuel combustion for 11 major world regions. The relative population of each world region is represented in Figure 1.4 by the area of the circle surrounding each data point. On this regional level there is a relatively strong correlation between per capita income and per capita emissions (as predicted by the IPAT identity), although some regions are slightly more or less carbon-intensive. On the other hand, population and greenhouse gas emissions are relatively unrelated, and around 15 per cent of the world’s population is responsible for almost half of global emissions. One of the most significant challenges facing the global energy system and climate is the potential impact on energy use and greenhouse gas emissions of economic development in developing countries, and the economically and socially desirable goal that they achieve levels of prosperity similar to those existing in developed countries today.

To better appreciate which activities are responsible for global emissions of CO₂, the principal GHG, and may pose the greatest threat to sustainability, Figure 1.5 shows global emissions according to the broad sector directly responsible for those emissions for the 30 years ending in 2000. The direct emissions from manufacturing, services and the residential sector have been roughly steady for 30 years, and most of the growth is apparently from electricity generation. This reflects the fact that the end-use sectors have shifted away from direct fuel combustion to greater use of electricity, because it is a flexible, convenient and clean fuel for the end user. The other source of emissions that is growing rapidly is transport, and in the last 30 years this sector accounted for almost all of the growth in energy emissions outside the electricity sector. Increasing emissions from road transport have driven much of this growth, and this mode accounted for close to 18 per cent of global CO₂ emissions from fossil fuel combustion in 2000, up from around 12 per cent in the early 1970s. Figure 1.5 shows that total annual CO₂ emissions from road transport increased from roughly 475 million tonnes of carbon (Mt C) in 1971 to almost 1130 Mt C in 2000. A continuation of these trends in emissions implies that transport, in particular road transport and private automobile use, may become one of the most substantial sources of greenhouse gas emissions in the future. This represents a potential challenge to long-term sustainable development, and identifies transport as an increasingly important target for mitigation policy intervention and technology deployment.

In the last 30 years over half of the growth in global road transport emissions occurred in OECD countries, and emissions originating from this
region represent an important existing threat to sustainable development. However, emissions from road transport have been growing much faster in many developing regions, as illustrated in Table 1.1, which shows that growth in non-OECD Asia outpaced that in the rest of the world, although even after three decades of rapid growth this region was still responsible for only 13.8 per cent of global emissions from road transport in 2000. These growth trends have important implications for medium- to long-term greenhouse gas emission abatement, and imply that the biggest future threats from transport to the goals of sustainable development are likely to emerge in today’s developing regions. Accordingly, realizing sustainable transport systems is a challenge confronting policy makers throughout the world.

1.2 RECENT TRENDS AND THE CURRENT STATE OF GLOBAL TRANSPORT ENERGY DEMAND

To assess the threats to sustainable development from future growth in greenhouse gas emissions from transport, it is necessary to identify the activities responsible for emissions in the transport sector. The latter is relatively straightforward, because almost all of the emissions from transport are
produced from the combustion of fossil fuels. Accordingly, the emission growth presented in Table 1.1 has been accompanied by a corresponding increase in transport energy use, which is illustrated in Figure 1.6. Figure 1.6 shows that road and air transport energy demand more than doubled between the early 1970s and 2000, consistent with the emissions growth shown in Table 1.1, whereas the combined energy use of rail, marine, pipeline and other transport barely changed (IEA, 2003a; IEA, 2003b). Private automobile travel volume during the same period increased to over 2.5 times the level in the early 1970s (based on Schafer and Victor, 2000; Schafer, 2003). By 2000, global final consumption of energy in the transportation sector had risen to just above 80 exajoules (EJ, 1018 joules), accounting for approximately 28 per cent of global final-energy consumption. Figure 1.7 illustrates regional differences in per capita transport energy demand, which is highest in developed regions such as North America (NAM), Western Europe (WEU) and the Pacific OECD (PAO). On the other hand, it is much lower in the least developed regions, including Centrally Planned Asia (CPA), South Asia (SAS) and Sub-Saharan Africa (AFR). This is important to bear in mind when exploring the possible impact of future economic development on transport activity and greenhouse gas emissions. Figure 1.7 also shows transport’s share of final-energy demand in different world regions.

Table 1.1 Road transport CO₂ emissions, historical regional shares and growth rates

<table>
<thead>
<tr>
<th>Region</th>
<th>Annual growth in emissions</th>
<th>Share of emissions</th>
<th>Share of global population</th>
</tr>
</thead>
<tbody>
<tr>
<td>OECD</td>
<td>2.9</td>
<td>2.0</td>
<td>2.1</td>
</tr>
<tr>
<td>Economies in transition Asia (non-OECD)</td>
<td>5.8</td>
<td>2.8</td>
<td>-2.4</td>
</tr>
<tr>
<td>Africa and Middle East Latin America</td>
<td>10.4</td>
<td>8.0</td>
<td>7.1</td>
</tr>
<tr>
<td>World total</td>
<td>4.0</td>
<td>2.6</td>
<td>2.6</td>
</tr>
</tbody>
</table>

regions, which ranges between roughly 11 and 38 per cent, although it should be recognized that this share is an indicator, of not only the importance of the transport sector in a given region, but also the size and energy intensity of other sectors, particularly manufacturing. Variation is also explained by regional geographic and infrastructure features, such as the organization of human settlements.

Of the 80 EJ of energy used by transport globally in 2000, almost 96 per cent comprised petroleum products, such as motor gasoline, diesel oil, kerosene jet fuel and so on, with the remaining fuel supplied by gas, biofuels (mainly ethanol), electricity and a small amount of coal (see Figure 1.8). Globally, the transportation sector consumed 60 per cent of all the petroleum products used by end-use sectors, and road vehicles accounted for 77 per cent of this petroleum consumption in 2000. Figure 1.8 shows that the remaining 23 per cent is divided mainly between air transport (12 per cent), mostly jet kerosene, and marine transport (10 per cent), primarily heavy diesel oil. Most of the small remainder is heavy diesel oil used in rail transport.

In developed regions, private automobile travel is estimated to account for around two-thirds of total road transport energy use (based on Landwehr and Marie-Lilliu, 2002; FHA, 1996; Davis and Diegel, 2004; IRF, 2000; EIA, 1999). Importantly, demand for private automobile travel is growing faster than total road transport energy demand, which itself
accounted for most of the historical increase in energy demand (and greenhouse gas emissions) from transport as a whole (see Figure 1.8). Accordingly, we pay special attention to passenger road vehicle transportation in Section 1.2.1.

Before doing so, we briefly discuss global consumption of non-petroleum fuels in the transport sector, which is summarized in Figure 1.9 (IEA, 2003a; IEA, 2003b). Apart from synthetic liquid fuels (mainly ethanol) derived from biomass feedstocks, these other fuels are used mainly in non-road transport. Bioethanol, in contrast, is used almost entirely in road transport where it is often blended – to various percentages – with gasoline to increase octane rating; the improved oxygenation also reduces emissions of some harmful pollutants. The second most important transport fuel after petroleum in the year 2000 was natural gas, which is used predominantly in pipeline transport (mainly for transportation of natural gas). Natural gas supplied less than 1 per cent of road transport demands in 2000. The remaining transportation sector demands were met by coal

Figure 1.7 Per capita energy consumption in the transportation sector in each world region, and percentage share of total final energy used in transportation, 2000


and electricity, both of which are used mainly in rail transport, although use of coal is declining and in 2000 it accounted for only 11 per cent of energy use in rail transport.

This broad historical snapshot of the transport sector highlights a number of key elements. Firstly, road transport dominates fuel consumption in the


Figure 1.8 Mix of fuels used in global transportation, and consumption of petroleum by different transport modes, 2000


Figure 1.9 Global biofuel, gas and electricity consumption and use in the transportation sector, in 2000
transport sector, and in developed regions around two-thirds of the energy used in road transport is consumed in private motor vehicle transport. Moreover, most of the growth in transport energy demand can also be attributed to road transport, and demand for passenger automobile transport is growing at a faster rate than overall road transport energy demand (Figure 1.6). Given the significance of private passenger transport, the rest of this chapter (and much of this book) focuses on this activity, particularly the implications for future car transport demand in a scenario of economic and social development outlined in Section 1.2.1.

1.2.1 Global Private Passenger Transport

As discussed, our focus on global private passenger transport is warranted because car travel demand is growing rapidly, contributing to the increasing overall road transport energy demand, which itself is responsible for an increasing share of energy consumption, and hence greenhouse gas emissions.

In 2000, most private passenger transport activity occurred in developed regions of the world. Table 1.2 presents the number of private passenger vehicles in this year for 11 world regions, estimated from a number of sources (AAMA, 1996; AAMA, 1997; FHA, 1996; Davis and Diegel, 2004; IRF, 2000; EIA, 1999; EIA, 2002). Globally, it is estimated that there were close to 600 million passenger vehicles (cars and light trucks used ostensibly as cars) in 2000, although there is some uncertainty regarding these figures, particularly for developing regions. Some 35 per cent of these vehicles could be found in North America, around 31 per cent in Western Europe and 10 per cent in the Pacific OECD countries. Thus, almost 77 per cent of all passenger vehicles are found in these three industrialized regions.

This concentration of vehicle ownership is also reflected in estimated ‘motorization rates’ (that is, vehicles per 1000 people). These are also shown in Table 1.2 and appear to correlate with per capita incomes, although other factors appear also to influence this relationship. Regional vehicle ownership rates vary from 660 per 1000 people in North America down to around five per 1000 people in South and Centrally Planned Asia (based on population figures from UN, 2004). For these regions it is important to note that the motorization rate estimates exclude two-wheeled vehicles, which are a relatively significant transport mode in many Asian countries; for example, in India and Indonesia two-wheelers outnumber cars by up to 5:1 (and the figure may be around 3:1 in China) (IRF, 2000). The global average motorization rate was estimated to be around 100 cars per thousand people in 2000.
One key question for exploring the possible emergence of a future sustainable transport system is whether economic development in today’s developing countries will lead to demands for the same levels of personal mobility that exist in today’s industrialized regions. The values in Table 1.2 provide some indication of how high future levels of global car ownership could rise, which in turn has implications for energy demand and greenhouse gas emissions. We explore this more concretely in later chapters.

### 1.3 THE ROLE OF TRANSPORT IN SUSTAINABLE DEVELOPMENT

Transforming global social and economic systems, including global energy and transport systems, from their current structure to one that is compatible with the goals of sustainable development is a long-term process involving continual change to a range of physical, technological and institutional systems. However, understanding how this long-term process might unfold...

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**Table 1.2  Estimated number of passenger vehicles (cars and light trucks used as cars), and number per 1000 persons in 2000**

<table>
<thead>
<tr>
<th>World Region</th>
<th>Passenger vehicle numbers (millions)</th>
<th>Motorization rates (PMV/1000 people)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America</td>
<td>211.1</td>
<td>660</td>
</tr>
<tr>
<td>Western Europe</td>
<td>188.3</td>
<td>410</td>
</tr>
<tr>
<td>Pacific OECD</td>
<td>60.5</td>
<td>403</td>
</tr>
<tr>
<td>Former Soviet Union</td>
<td>18.1</td>
<td>62</td>
</tr>
<tr>
<td>Eastern Europe</td>
<td>18.0</td>
<td>148</td>
</tr>
<tr>
<td>Centrally-Planned Asia</td>
<td>6.9</td>
<td>4.9\textsuperscript{a}</td>
</tr>
<tr>
<td>South Asia</td>
<td>7.4</td>
<td>5.4\textsuperscript{a}</td>
</tr>
<tr>
<td>Other Pacific Asia</td>
<td>26.3</td>
<td>55\textsuperscript{a}</td>
</tr>
<tr>
<td>Latin America</td>
<td>41.8</td>
<td>81</td>
</tr>
<tr>
<td>Middle East and North Africa</td>
<td>11.8</td>
<td>34</td>
</tr>
<tr>
<td>Sub-Saharan Africa</td>
<td>9.5</td>
<td>15</td>
</tr>
<tr>
<td>World</td>
<td>599.7</td>
<td>99 (avg.)</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Note that in these regions two-wheelers represent a very substantial part of the private vehicle fleet. For example, in China, India and Indonesia, it is estimated that there are 3 to 5 times as many motorized two-wheelers as there are cars. Accordingly, the level of private mobility is underestimated if one considers car numbers alone.

**Source:** Estimates based on AAMA, 1996; AAMA, 1997; FHA, 1996; Davis and Diegel, 2004; IRF, 2000; EIA, 1999; UN, 2004.
can help guide policy responses aimed at achieving the long-term strategic goals of sustainable development. One way to explore a possible trajectory for the transformation of the global energy and transport system is with long-term (until 2100) energy–economy–environment (E3) scenarios. Such scenarios are useful for enhancing our understanding of highly complex systems, of which energy and transport are prime examples. Importantly, scenarios are not intended to be predictions, but enable us to explore plausible questions of ‘what if’ related to key future uncertainties. They can also illustrate some of the possible impacts of today’s policy and technology decisions, and are therefore an essential tool for policy makers confronting long-term challenges.

In this book an E3 scenario is used to explore a number of issues related to the role of private transport and personal mobility in sustainable development. Importantly, a single E3 scenario can only represent one configuration of the future, while significant social, economic, environmental, technological and political uncertainties mean that many pathways are possible. An extensive sensitivity analysis of the impact of these uncertainties on possible transformations of the global energy system would provide useful insights for designing robust strategies for realizing sustainable development. However, a single scenario that is carefully defined, internally consistent and intuitively plausible can provide important additional insights about technological developments and possible targets for policy support. With this in mind, this analysis focuses on carefully describing a single ‘core’ scenario of sustainable development, while also examining some of the elements that contribute to the significant levels of uncertainty – particularly social and political – by also exploring some alternative pathways in which decision makers place a lower priority on sustainable development.

One of the specific questions we will attempt to address with these E3 scenarios is whether the level of personal mobility in developed regions, and achieving the mobility aspirations of the developing world, is inconsistent with sustainable development. Moreover, we will explore the technology pathways for transport that are most compatible with sustainable development. Importantly, however, we do not intend to explore all aspects of sustainable development, which covers a very broad range of activities and goals, but rather focus on those most relevant to energy and transport systems, such as climate change mitigation, as discussed above. Accordingly, we examine here in detail only a limited set of necessary conditions for achieving sustainable development based on four key principles that can be applied to E3 scenarios (see Box 1.1).
Sustainable development is a widely accepted principle in the design of long-term energy–economy–environment (E3) strategies. Despite a broad consensus on the general idea of sustainability, varying degrees of agreement exist on specifics, in particular on trade-offs between incommensurable objectives.

In an effort to perhaps contribute one step to a possible future consensus in the field of sustainable development, IIASA–ECS has proposed a working definition of sustainable-development E3 scenarios. This working definition consists of quantitative criteria, which can be used to classify long-term E3 scenarios, covering economic and environmental sustainability as well as inter- and intra-generational equity (Klaassen et al., 2002).

More specifically, we define sustainable development scenarios as those that meet the following four criteria.

1. Economic growth (GDP/capita) is sustained throughout the time horizon of the scenario.
2. Socioeconomic inequity among world regions, expressed as the world-regional differences of GDP (gross domestic product) per capita, is reduced significantly over the 21st century, in the sense that, by 2100, the per capita income ratios between all world regions are reduced to ratios close to those prevailing between OECD countries today.
3. Long-term environmental stress is mitigated significantly. In particular, carbon emissions at the end of the century are approximately at or below today’s emissions. Other GHG emissions may increase, but total radiative forcing, which determines global warming, is on a path to long-term stabilization. Other long-term environmental stress to be mitigated includes impacts on land use, for example desertification. Short- to medium-term environmental stress (for example, acidification) may not exceed critical loads that threaten long-term habitat well-being.
4. The reserves-to-production (R/P) ratios of exhaustible primary energy carriers do not decrease substantially from today’s levels.
However, it must be emphasized that these criteria cover only a part of the full spectrum of sustainable development, and are of limited applicability for assessing some elements of and challenges to sustainability, such as biodiversity, desertification, ozone layer depletion and others.

This analysis will then seek to determine whether establishing a sustainable transport system based on the four fundamental principles in Box 1.1 will, for instance, require restrictions on mobility or access to particular transport modes, or if technological development can overcome the negative effects of transportation.

The future choice of technologies will clearly be one critical element for achieving a gradual transformation to an environmentally sustainable world. New technologies have a substantial potential and can play an essential role in any transition to a sustainable future, and deserve particular attention. Accordingly, in subsequent chapters of this book we investigate in detail the transport sector technologies and energy carriers most characteristic of sustainable development (see Ausubel et al., 1998; Nakićenović, 1991). These can include, on the one hand, technologies that represent a significant departure from today’s fossil-based systems, and which may be well-suited for the very long term. On the other hand, there are also ‘bridging’ technologies, which, while compatible with the dominant structure of the global energy system, pave the way for the transition towards sustainable energy futures. The early identification of those technologies with the potential to accelerate or help overcome potential barriers to the transition to a sustainable energy system is essential for providing guidance to policy makers about the most appropriate forms of policy support needed to achieve long-term sustainability strategies (Klaassen et al., 2002).

Within this context there has been a substantial debate on the role of hydrogen (H₂) fuel and fuel cell (FC) cars in a strategy to mitigate GHG emissions, particularly on the timing of this option (see for example Keith and Farrell, 2003; Azar et al., 2003). It has been argued that climate change mitigation, among others, could be a reason to support the early introduction of these technologies. However, these are very immature and expensive technologies and much of the necessary supporting infrastructure does not yet exist, making it difficult to see how a so-called ‘hydrogen economy’ could emerge. This is one of the many questions that the analysis in subsequent chapters will seek to explore.

Moreover, energy systems based on alternative fuels, including hydrogen (to use the example above) are not necessarily more sustainable in terms of
greenhouse gas emissions, since they are often energy-intensive and may rely on other fossil fuels. This highlights the fact that the transport sector cannot be examined in isolation of the rest of the energy system, so in the following chapters we will also explore the broader energy system developments, particularly in terms of fuel production, required for the emergence of a sustainable passenger transport sector. This analysis will provide some insights regarding the technologies that should be the target of increased R&D and commercialization support. The results aim to provide a 'technological road map to sustainable development', focusing specifically on the transportation sector.

Given this overall plan, the remainder of this book is organized as follows. After this introductory chapter, Part I of this book comprises two chapters exploring future transport demands and technology prospects. In the first half of Chapter 2 we describe the basic economic, demographic and other features that form the basis for developing a sustainable transport scenario. The remainder describes the construction and features of an accompanying, consistent travel demand scenario, and vehicle market characteristics. Chapter 3 then examines the characteristics, current status and future prospects for a range of vehicle and fuel technologies, compatible with sustainable development and otherwise. In Part II we combine the elements presented in this introduction and Part I to present a selection of detailed transport technology scenarios. We start in Chapter 4 by first presenting the analytical framework applied to assess long-term technology potential in a sustainable energy and transport scenario. Chapter 5 then describes such a scenario, and examines the role of different vehicle technologies and the impact on greenhouse gas emissions. In Chapter 6 we investigate alternative scenarios of future transport technology deployment, including one where sustainable development is largely ignored and commercial potential alone (under current institutions and incentives) determines technology choice. This complements Chapter 5, which describes a possible technological roadmap to sustainable development, by identifying those technologies likely to require support to achieve commercialization.

Since policy initiatives are likely to be of critical importance in achieving the goals of sustainable development in the transport sector, including greenhouse gas abatement, in Part III we look in detail at the suite of policy instruments, measures and other agreements in place or under consideration to mitigate greenhouse gas emissions from transport. We focus especially on initiatives in Europe and Japan, since these regions are relatively advanced in incorporating environmental assessment and objectives into policy design and implementation. Chapter 7 presents a general overview of the range of policy instruments suitable for GHG abatement in
the automobile sector, while Chapter 8 explores in detail market-based
demand-side instruments, which are attracting increasing attention among
policy makers. Complementing this demand-side policy analysis, we also
examine supply-side initiatives, focusing in Chapter 9 on voluntary or nego-
tiated agreements. Chapter 10 then discusses the role of supply-side
support related to R&D support and investment leading to technological
development, which is another important element of any strategy to
address the long-term challenges emerging in the global transport sector.

Part IV presents a 'road map' to achieve a sustainable transport scenario
by synthesizing, in Chapter 11, the findings of the analysis from Part II on
technology developments in transport with the review of transport policy
instruments in Part III. Chapter 12 and Chapter 13 explore the role of a
variety of policy instruments in implementation of the technological
roadmap described in earlier sections, and derive critical policy insights for
achieving sustainable automobility and reducing GHG emissions.

NOTES

1. We use the term ‘fossil fuels’ throughout to refer to carbon fuels of geological origin,
including coal, gas and oil. However, this term may not be entirely correct since there is
some evidence that some geological stores of carbon fuels are of abiogenic origin (see
summary in Odell, 2004, ch. 6).

2. The definition of OECD used here includes only those countries who were members of
the Organisation in 1990, and therefore excludes newer entrants such as Mexico, South
Korea, Poland, the Czech Republic, Hungary and Slovakia.

3. Electricity's share of final-energy consumption increased from 10 to almost 16 per cent

4. So, although the shares are high in developed regions (NAM, WEU and PAO) and low in
the least-developed regions (SAS and AFR), transport’s share of final energy use in moder-
ately developed regions, such as the economies in transition (FSU and EEU) is low
partly because of the higher energy intensity of other end-use sectors. Conversely, regions
such as Latin America (LAM), the Middle East (MEA) and Other Pacific Asia (PAS) have
a share almost as high as the developed regions because energy use in other sectors is rela-
tively small, even though per capita energy demand in transport is much lower in these
regions.

5. Note that this includes also fuels used for international air and marine transport.

6. Private passenger transport can normally be thought of as car transport. However, in
North America a majority of the light vehicles sold in recent years have been light-duty
trucks instead of cars (with light trucks accounting for 52.8 per cent of light vehicle sales
in 2003, according to Davis and Diegel (2004, Table 4.9)). Since most of these are used for
personal transport (75 per cent in 1997, based on Davis and Diegel (2004, Table 5.7)), it
is more accurate to use the broader term ‘private passenger vehicle’. For convenience,
however, we will use this term and the term ‘car’ interchangeably to cover private passen-
ger vehicles.

7. And probably around 800 million of all types of road vehicles with four wheels or
more (based on the same sources). In developing regions, commercial vehicles represent a
much larger share of total vehicle fleet than in developed regions (AAMA, 1997; IRF,
2000).
8. For example, region-specific factors are apparent for North America, where vehicle ownership rates are more than 50 per cent above those in other industrialized regions, and in sub-Saharan Africa, which has a higher vehicle ownership rate than the relatively richer South Asian and CPA regions, although lower numbers of two-wheelers.