Ecofys BV
P.O. Box 8408
NL-3503 RK Utrecht
Kanaalweg 16-G
NL-3526 KL Utrecht
The Netherlands
www.ecofys.com

T +31 (0)30 280 83 00
F +31 (0)30 280 83 01
E info@ecofys.com

GLOBAL LOW ENERGY DEMAND SCENARIOS 2003-2050

Wina Graus
Mirjam Harmelink

August 2006
Project number: ECS05100

by order of:
Deutsches Zentrum für Luft- und Raumfahrt (DLR)

Table of contents

1 Introduction

1.1 Background

DLR has been asked by Greenpeace International and EREC to conduct a study on global sustainable energy pathways up to 2050. This study should result in energy scenarios with emissions that are significantly lower compared to current levels. The scenarios will be presented on the EREC policy conference in January 2007 in Brussels.

The energy supply scenarios will be calculated using the MESAP/PlaNet simulation model that was used before for a similar study by DLR on the EU-25 scenario "Energy revolution: A sustainable pathway to a clean energy future for Europe" published in September 2005 for Greenpeace International. DLR asked Ecofys to develop the energy demand scenarios for this study.

1.2 Aim of the study

The aim of this project is to develop low energy demand scenarios for the period 2003 to 2050 on a sectoral level for the IEA regions. The years taken into account are 2010, 2020, 2030, 2040 and 2050.

The scenarios are based on the reference scenario from IEA World Energy Outlook (2004). The energy demand is split up in electricity and fuels[1]. The sectors that will be taken into account are industry, transport and others (including households and services).

Two low energy demand scenarios will be developed based on the IEA reference scenario:

1. An ambitious energy efficiency scenario and
2. A more economic energy efficiency scenario

---

[1] This includes energy demand in terms of fossil fuels, renewable energy sources and heat. Feedstocks are excluded.

1.3 Contents of the report

First (Chapter 2) discusses the approach and methodological issues. Next, Chapter 3 provides a description of the energy savings options included in the analysis. For each option a short description is provided as well as the basic assumptions and resulting reduction potential. Chapter 4 discusses the results of the analysis.

2 Approach

2.1 Introduction

This chapter includes a description of the approach and assumptions used in this study. Figure 1 shows the steps taken in this study to develop the low energy demand scenarios.

Step 1: Reference scenario
The purpose of step one is to develop a reference energy demand scenario for the period 2003-2050 per region and per sector.

Step 2: List of measures
In step two a list is drawn up of possible energy savings options per sector.

Step 3: Energy savings potential
Step three aims to determine the energy savings potential per year evaluated (2010, 2020, 2030, 2040 and 2050) and per sector. A distinction is made between the economic and the technical energy savings potential, leading to two low energy demand scenarios:

1. *Ambitious.* This is an ambitious energy efficiency scenario focusing on current best practice technologies and available technologies in the future. This scenario assumes continuous innovation in the field of energy efficiency.
2. *Constraint.* This is a scenario with more moderate energy savings taking into account implementation constraints of energy efficient technologies in terms of costs and other barriers.

Figure 1 Steps taken within the project

The regions included in this analysis are given in Table 1.

Table 1 Specification of world regions (IEA 2004)

World region	Countries
OECD Europe	Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovak Repub-

World region	Countries
	lic, Spain, Sweden, Switzerland, Turkey, United Kingdom
OECD North America	Canada, Mexico, United States
OECD Pacific	Japan, South Korea, Australia, New Zealand
Transition Economies	Albania, Bosnia-Herzegovina, Bulgaria, Croatia, Federal Republic of Yugoslavia, Macedonia, Romania, Slovenia, Cyprus, Gibraltar[1)], Malta[1)] and Former USSR (Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Republic of Moldova, Russia, Tajikistan, Turkmenistan, Ukraine and Uzbekistan)
China	China (including Hong Kong)
East Asia	Afghanistan, Bhutan, Brunei, Cambodia, Chinese Taipei, Fiji, French Polynesia, Indonesia, Kiribati, Democratic People's Republic of Korea, Laos, Malaysia, Maldives, Myanmar, New Caledonia, Papua New Guinea, Philippines, Samoa, Singapore, Solomon Islands, Thailand, Vietnam, Vanuatu
South Asia	Bangladesh, India, Nepal, Pakistan, Sri Lanka
Latin America	Antigua and Barbuda, Argentina, Bahamas, Barbados, Belize, Bermuda, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Domenica, Dominican Republic, Ecuador, El Salvador, French Guiana, Grenada, Guadeloupe, Guatemala, Guyana, Haiti, Honduras, Jamaica, Martinique, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, Puerto Rico, St. Kitts-Nevis-Anguila, Saint Lucia, St. Vincent-Grenadines and Suriname, Trinidad and Tobago, Uruguay, Venezuela
Africa	Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Congo, Democratic Republic of Congo, Cote d'Ivoire, Djibouti, Egypt, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Libya, Madagascar, Malati, Mali, Mauritania, Mauritius, Marocco, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, United Republic of Tanzania, Togo, Tunisia, Uganda, Zambia, Zimbabwe
Middle East	Bahrain, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syria, United Arab Emirates, Yemen

[1)] Allocation of Gibraltar and Malta to Transition Economies because of statistical reasons

The sectors distinguished in this analysis are industry, transport and others. These sectors correspond to the sectors given in the IEA World Energy Outlook. In the World Energy Outlook, total final consumption is broken down into the following sectors: industry, transport, other (includes agriculture, residential, commercial and public services). For industries, feedstocks are excluded in the analysis.

2.2 Step 1: reference scenario

The reference scenario is defined as the development in final energy demand up to 2050, assuming:

1. No large changes take place in the production and consumption structure of the current economy
2. All currently adopted energy and climate change policies are implemented.

The purpose of this step is to determine the reference final energy demand for the years 2010, 2020, 2030, 2040 and 2050. The base year of the analysis is 2003.

2.2.1 Reference scenario 2010, 2020 and 2030

The energy demand in 2010, 2020, 2030 is taken from IEA World Energy Outlook 2004 (WEO). The energy demand for industries is corrected for feedstock use.

2.2.2 Reference scenario 2040 and 2050

The energy demand in 2040 and 2050 is based on extrapolation of the World Energy Outlook reference scenario to the years 2040 and 2050. The extrapolation is based on:

- The growth rate of GDP[2] per capita and population for the period 2030-2050 (Krewitt and Kronshage, 2006)
- Autonomous energy intensity[3] decrease

Total final energy consumption is a result of the final energy consumption per capita in 2040 and 2050 and the population in 2040 and 2050. The growth rate for final energy consumption per capita is based on the increase of GDP per capita corrected for the autonomous energy intensity decrease.

The autonomous energy intensity decrease differs per regions and is based on the development of final energy intensity per region in 2002-2030 from World Energy

---

[2] GDP corrected for Purchase Power Parity (PPP)

[3] Energy intensity is a measure of total primary energy use per unit of gross domestic product.

Outlook. The trend for the autonomous energy intensity development in the periods 2010-2020 and 2020-2030 is linearly extrapolated to the period 2030-2050.

We assume that the relative growth trends per sector in the period 2020-2030 continue in the period 2030-2050. For instance, if the share of transport in total final energy consumption grows by 15% in the period 2020-2030 we assume that the same growth trend will be present in the period 2030-2040 and 2040-2050.

Figure 2 shows the reference scenario for the world.

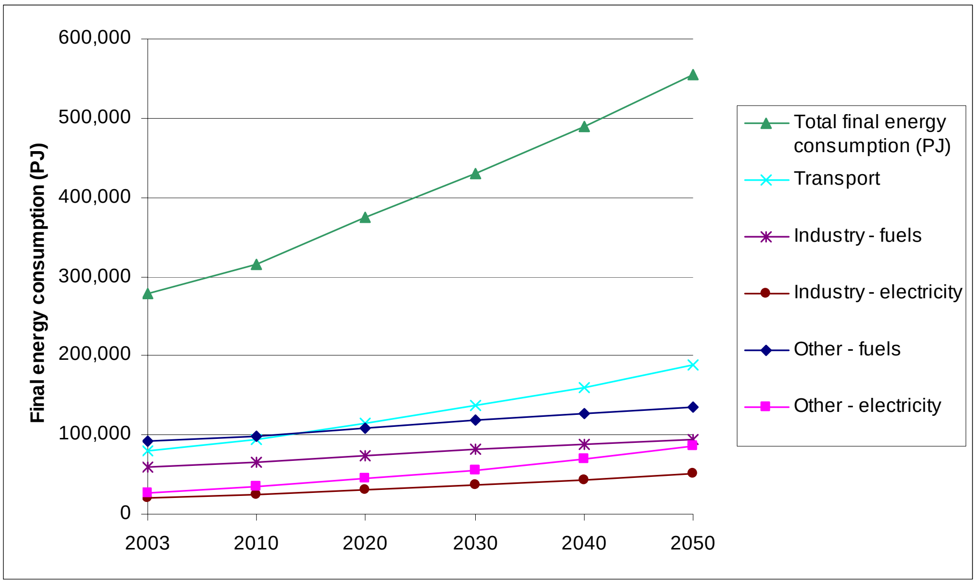

Figure 2 Reference scenario World

2.3 Step 2: List of measures

Table 2 shows the measures analysed in this study. The list of options is derived from a number of projects previously executed by Ecofys [Ecofys, 2001 and 2003]. Options are selected, which are expected to result in a substantial reduction of energy demand before 2050. In most cases state of the art technologies are selected and not technologies that are currently in a development state.

Table 2 Overview of measures assessed in this study

Sector	**Nr.**	**Reduction option**
Industry		
General	1	Efficient motor systems

Sector	**Nr.**	**Reduction option**
General	2	Heat integration / pinch analysis
General	3	Improved process control
Aluminium	4	Increase secondary aluminium
Iron and steel	5	Blast furnace – coal injection
Iron and steel	6	BOF gas + sensible heat recovery
Iron and steel	7	Thin slab casting
Chemical industry	8	Membrane product separation
Other industries	9	Energy efficiency improvement
Transport		
Passenger cars	1	Efficient passenger cars (hybrid fuel cars)
Freight	2	Efficient freight vehicles
Buses	3	Efficient buses
Others		
Households and services	1	Efficient electric appliances
Services	2	Efficient cooling equipment
Households and services	3	Efficient lighting
Households and services	4	Reduce stand-by losses
Households and services	5	Improved heat insulation
Services	6	Reduce electricity use during non-office hours
Agriculture and non-specified others	7	Energy efficiency improvement

2.4 Step 3: Energy savings potential

The energy savings potential of a measure is based on the estimated energy savings in comparison to the reference scenario. The resulting energy savings of a certain option is thus additional to energy-efficiency improvement already occurring in the reference scenario. Table 3 shows the parameters that are used to calculate the energy savings per measure.

Table 3 Parameters used for calculating energy savings per measure

Indicator	**Definitions**
Reference final energy demand	Final energy demand by sub sector in baseline
Reduction efficiency (%)	Reduction of final energy demand after the measure is applied in comparison to situation where the measure is not applied.
Energy savings (%)	The energy savings are given in comparison to the reference energy demand of a sub sector. The implementa-

	tion potential of a measure and the implementation of a measure in the reference scenario are taken into account.

The measures are defined in such a way that there is no overlap between the measures. This means that the total savings of final energy demand can be determined by adding the energy savings of the separate options.

Two scenarios are distinguished: Ambitious and Constraint.

1. Ambitious. This is an ambitious energy efficiency scenario focusing on current best practice technologies and available technologies in the future. This scenario assumes continuous innovation in the field of energy efficiency. The resulting energy savings potential in this scenario reflects the total energy savings potential of the measures that is considered technically feasible, while taking into account stock turnover rates and life span of equipment and installations. This means that equipment or cars are replaced at the end of their economic life time.
2. Constraint. This is a scenario with more moderate energy savings taking into account implementation constraints of energy efficient technologies in terms of costs and other barriers.

2.5 Uncertainties in results

A number of assumptions need to be made in these analyses, which lead to uncertainties in the results. These assumptions are mainly:

- Assumptions for extrapolation of the reference scenario.
- Assumptions for determining costs and energy savings potential of the measures.
- Assumptions for determining the implementation of the measures in the reference scenario and the possible implementation of the measures in the two low energy demand scenarios.

The uncertainties resulting from the assumptions add up to significant uncertainties in the results. This means that the results should be interpreted as order of magnitude numbers.

3 Reduction options

3.1 Introduction

This chapter contains an overview of current energy use per sector and a general description of the energy savings measures considered within this project. The description includes the general assumptions made to determine the energy saving potential.

Figure 3 shows a breakdown of final energy demand in the world by the most important sub-sectors in the base year 2003.

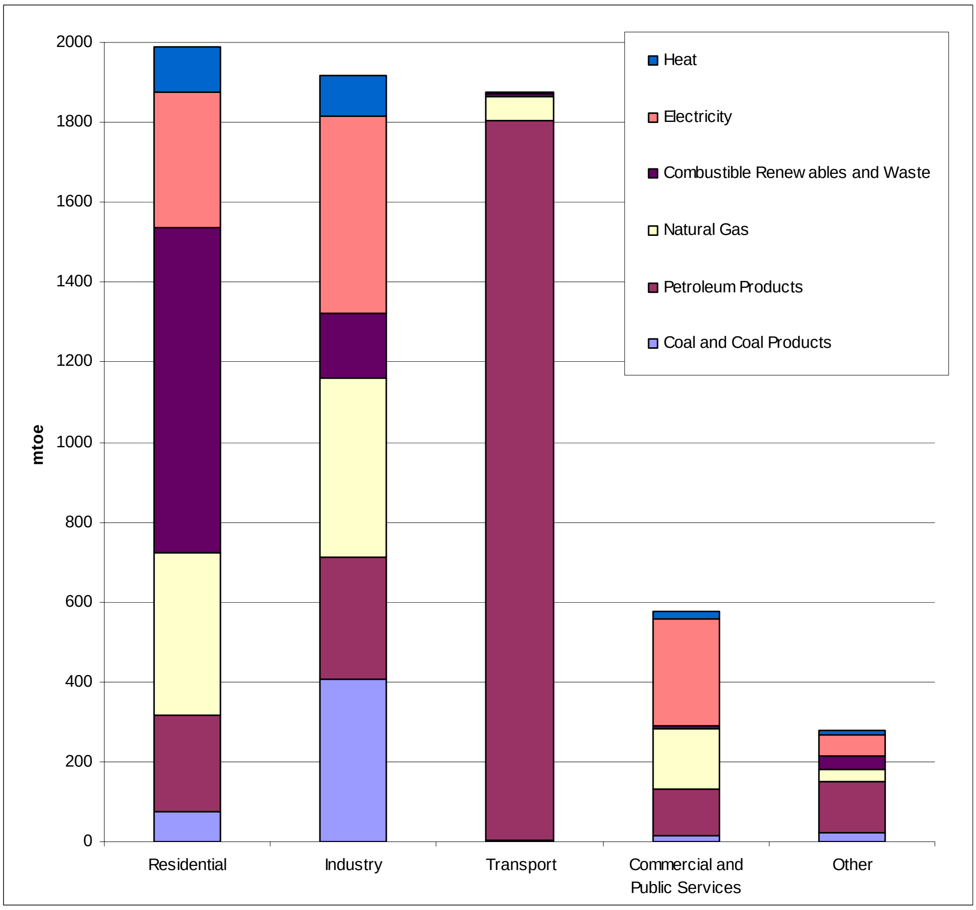

Figure 3 Final energy demand for the world by sub sector and fuel source in 2003 (IEA, 2005)

3.2 Industry

Figure 4 shows a breakdown of final energy demand per sub sector in industry for the base year 2003.

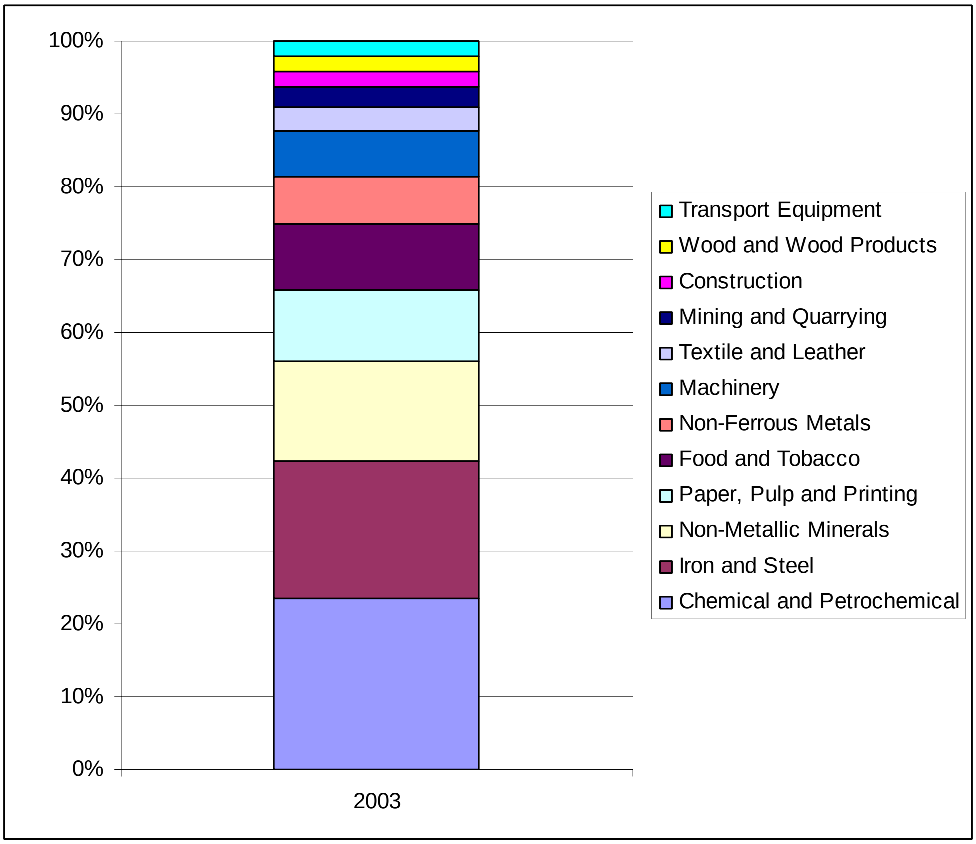

Figure 4 Breakdown of final energy consumption in 2003 by sub sector for industry (IEA, 2005)

We assume that the share of final energy demand per sub sector in the base year remains the same in future years.

For industry we look at eight measures for improving energy efficiency. Three general measures that are applicable to all industries are

- Efficient motor systems
- Process optimization and integration
- Improved monitoring and process control

Sector specific measures are

- Aluminium
    - recycling of aluminium
- Iron and steel
    - Blast furnace – coal injection
    - Basic Oxygen Furnace (BOF) – BOF gas and sensible heat recovery
    - Thin slab casting
- Chemical industry
    - Membrane product separation

1. Efficient motor systems

Electric motors systems in the industry make up a large share of the electricity use in industry. Approximately 65% of the electricity use by industry is used to drive electric motor systems. Ways of reducing electricity consumption in electric motor systems are:

1. Variable Speed Drives (VSDs). VSDs can lead to savings of electricity consumption of 15% to 35% of the electricity consumption of electric motor systems (EC, 1999). VSDs can be applied in approximately 40% to 60% of the cases.
2. High Efficiency Motors (HEMs). HEMs reduce energy losses through improved design, better materials, tighter tolerances, and improved manufacturing techniques. The specific energy savings depend on the efficiency of the current motor. For large motors the savings are likely to be small (1-2%) and for smaller motors larger (up to 75%) (Keulenaer et al, 2004). On average HEMs lead to an electricity savings of 3% to 5% (UU, 2001).
3. Implementing efficient pumps, compressors and fans.
    a. A case study has shown that 25% of the electricity consumption of a compressor can be saved by measures as process control, heat recovery and improvement of air treatment. Compressors account for about 15% of the electricity consumption of industrial motor systems. (Keulenaer et al, 2004)
    b. A case study has shown that 30% of the electricity consumption of a pump system can be saved by adapting the design. The payback time is twelve weeks. Pumps account for about 35% of electricity consumption of industrial motor systems. The technical electricity savings potential for conventional pumping systems is 55%. This includes low friction pipes, with an efficiency of 90% in comparison to 69% for conventional pipes. (Keulenaer et al, 2004)

c. The payback time of efficient fans is estimated to be 0.4 years (Keulenaer et al, 2004). Fans account for about 15% of electricity consumption of industrial motor systems. (Keulenaer et al, 2004)

Together these measures lead to a technical electricity savings potential of 40%. According to a study for EU-15, the economic savings potential is 29% of the electricity consumption for industrial motor systems (Keulenaer et al, 2004). The economic savings potential includes measures with payback times up to three years.

In this study the technical electricity savings potential by 2050 is estimated to be 40% and the electricity savings potential for the Constraint scenario is estimated to be 30% of the electricity consumption of industrial motor systems. We assume that all motor systems can be replaced by 2030, with a linear implementation for the previous years.

2. Process Optimization and Integration (pinch analysis)

Process integration or pinch technology refers to the exploitation of potential synergies that are inherent in any system that consists of multiple components working together. In plants that have multiple heating and cooling demands, the use of process integration techniques may significantly improve efficiencies.

The methodology involves the linking of hot and cold streams in a process in a thermodynamic optimal way (i.e. not over the so-called ‘pinch’). Process integration is the art of ensuring that the components are well suited and matched in terms of size, function and capability.

The energy savings potential using pinch analysis far exceeds that from well-known conventional techniques such as heat recovery from boiler flue gas, insulation and steam trap management. There is usually a large potential for improvement in overall site efficiency through inter-unit integration via utilities, typically 10 to 20% at a two-year payback. (Kumana, 2000) A number of refineries have applied total site pinch analysis. Typical savings identified in these site-wide analyses are around 20-30%, although the economic potential was found to be limited to 10-15% (Linnhoff March, 2000).

For this study we assume that pinch analysis can reduce heat demand of industries by 10% economically and 20% technically. The implementation of pinch analysis in the reference scenario is assumed to be 25%, leaving an additional potential of 75% of the industry to which pinch analysis can still be applied. We assume that in 2020 all sites can have pinch analysis implemented with a linear implementation for the previous years.

3. Improved monitoring and process control

The use of energy monitoring and process control systems can play an important role in energy management and in reducing energy use. Typically, energy and cost savings are around 5% or more for many industrial applications of process control systems (Worrell and Galitsky, 2005). Although, energy management systems are already widely disseminated in various industrial sectors, the performance of the systems can often still be improved. In many cases, only one process or a limited number of energy streams were monitored and managed. Various suppliers provide site-utility control systems (HCP, 2001). Payback times range generally from 6 to 18 months (Worrell and Galitsky, 2005).

A variety of process control systems are available for virtually any industrial process. Below is an overview of process control systems.

System	**Characteristics**	**Typical energy savings (%)**
Monitoring and Targeting	Dedicated systems for various industries, well established in various countries and sectors	Typical savings 4-17%, average 8%
Computer Integrated Manufacturing (CIM)	Improvement of overall economics of process, e.g. stocks, productivity and energy	> 2%
Process control	Moisture, oxygen and temperature control, air flow control “Knowledge based, fuzzy logic”	Typically 2-18% savings

Sources: Martin et al. (2000) and Worrell and Galitsky (2005)

We assume that energy savings from improved monitoring and process control are 5% of industrial energy demand and can be fully implemented from 2010 onwards. All savings are assumed to be economic.

Aluminium

4. Recycling of aluminium

The production of primary aluminium from alumina (which is made out of bauxite) is a very energy-intensive process. It is produced by passing a direct current through a bath with alumina dissolved in a molten cryolite electrode. Another option is to produce aluminium out of recycled scrap. This is called secondary production. Secondary aluminium uses only 5 to 10% of the energy demand for primary production because it involves remelting of the metal instead of the electrochemical reduction process (Phylipsen et al., 1998).

Anything made of aluminium can be recycled repeatedly; cans, aluminium foil, plates and pie moulds, window frames, garden furniture and automotive components can be melted down and used to make similar products again. The recycling of aluminium beverage cans eliminates waste. It must be noted that the share of secondary aluminium production cannot be increased infinitely, because the product quality is affected by the use of scrap as a feedstock. For some high quality products new aluminium still needs to be used.

Just over 5 million tonnes of old and new scrap were recycled in 2005 worldwide, which fulfilled 22% of the global demand for aluminium.[4] Of the total amount of recycled aluminium, approximately 17% comes from packaging, 38% from transport, 32% from building and 13% from other products. Recycling rates for building and transport applications range from 60-90% in various countries. Recycling rates can be further increased e.g. by improved recycling of aluminium cans. In Sweden, 92% of aluminium cans are recycled and in Switzerland 88%. The European average is 40%.

We assume that by 2050, 50% of primary aluminium production can be reduced by increased recycling of aluminium, bringing the share of recycled aluminium to 60% of total aluminium production. This saves 45% of the electricity consumption for primary aluminium production (assuming secondary aluminium uses 10% of the energy demand for primary production). For the Constraint scenario we assume that 40% of primary aluminium production can be reduced by increased recycling.

Primary aluminium production and associated electricity consumption per region is given in Table 4.

---

[4] http://www.world-aluminium.org/iai/stats/

Table 4 Primary aluminium production per region in 2004[5]

Region	**Primary aluminium production (1000 tonnes)**	**Electrical power used (MWh/tonne)**	**Electricity consumption (TWh)**	**Share in electricity consumption industry (%)**
OECD Europe	4607	15.3	70	6%
OECD North America	5108	15.6	80	6%
OECD Pacific	2257	14.8	33	5%
Transition Economies	4624	15.3	71	14%
China	6670	15.3[6]	0	9%
East Asia	230	15.4	4	1%
South Asia	862	15.4	13	6%
Latin America	2351	15.6	37	11%
Africa	1702	14.3	24	12%
Middle East	1383	15.3[7]	0	21%
World	*29794*	*15.3*	*455*	*7%*

We assume that the share of electricity consumption for aluminium production in total electricity consumption for the sector industry remains the same per region up to 2050.

Iron and steel

The iron and steel industry is made up of (1) integrated steel mills that produce pig iron from raw materials (iron ore and coke) using a blast furnace and produce steel using a basic oxygen furnace (BOF) or an Open Hearth Furnace (OHF), and (2) secondary steel mills that produce steel from scrap steel, pig iron, or direct reduced iron (DRI) using an electric arc furnace (EAF). The majority of steel produced in the world is from integrated steel mills, although the share of secondary steel mills (or “minimills”) is increasing, growing to 40% in 2005[8].

There are a number of options for reducing energy consumption in the iron and steel sector. Below are three important options.

---

[5] http://www.world-aluminium.org/iai/stats/
http://minerals.usgs.gov/minerals/pubs/commodity/aluminum/alumimyb04.xls

[6] Assumption

[7] Assumption

[8] http://www.worldsteel.org/?action=stats&type=steel&period=year&year=2005

5. Blast furnace- coal injection

An average coal injection rate of 180 kg/t hot metal leads to fuel savings of 1.1 GJ/tonne hot metal (Farla et al., 1998) with a payback time of approximately 4.5 years (IEA, 1995). Injection of pulverized coal may lead to reduced capacity utilization of the blast furnace (Hanes, 1999). Hence, the economic benefits may vary by plant.

Currently, coal is seen as the favourable injection fuel because of its low price. Injection of natural gas is an alternative. Maximum injection rates are lower than for coal (Oshnock, 1995b). This technology is applied in a number of plants, but can be much more widespread.

6. Basic Oxygen Furnace - BOF gas + sensible heat recovery

BOF gas and sensible heat recovery (suppressed combustion) is the single most energy-saving process improvement in this process step, making the BOF process a net energy producer. By reducing the amount of air entering over the converter, the CO is not converted to CO_2. The sensible heat of the off-gas is first recovered in a waste heat boiler, generating high pressure steam. The gas is cleaned and recovered.

The total savings vary between 535 and 916 MJ/tonne crude steel, depending on the way the steam is recovered (Stelco, 1993). Suppressed combustion reduces dust emissions and since the metal content of the dust is high, about 50% of the dust can be recycled in the sinter plant (Stelco, 1993).

The costs will depend on the need for extra gas holders. Suppressed combustion is very common in integrated steel plants in Europe and Japan.

7. Thin slab casting

Thin slab casting is a new technology integrating casting and hot rolling in one process. Pioneered in the U.S. by Nucor at the Crawfordsville and Hickmann plants, various plants are operating, under construction, or ordered worldwide. Originally designed for small scale process-lines, the first integrated plants constructed (Acme, U.S.; Posco, Korea) or announced the construction of thin slab casters (Germany, Netherlands, Spain) with capacities up to 1.5 Mt/year (Worrell and Moore, 1997). Energy savings are estimated to be 3 GJ/tonne crude steel (Worrell, 1999).

Table 5 shows iron and steel production by region.

Table 5 Iron and steel production by region in 2004

	Iron production (mtonnes)		**Steel production (mtonnes)**			
	Pig iron	**DRI**	**OHF steel**	**BOF steel**	**EAF steel**	**Total crude steel production**
OECD Europe	113	0.7	0	124	90	215
Transition economies	88	3	32	72	19	123
OECD North America	49	1	0	62	71	133
Latin America	39	19	0	29	17	47
Africa	7	6		7	9	17
Middle East	2	11	0	2	12	14
China	329	0.4	0	224	50	272
South Asia	26	9	2	18	14	34
East Asia	10	3	0	11	23	34
OECD pacific	117	1	0	116	52	169
World	***780***	***53***	***34***	***664***	***359***	***1058***

Sources: IISI statistical yearbook 2005[9]

Table 6 shows specific energy consumption for iron and steel production by region. The most energy intensive part of steel making is the production of pig iron and direct reduced iron (DRI). The higher the share of pig iron and DRI in total steel production (i.e. the lower the share of scrap input used) the higher the specific energy consumption.

Table 6 Specific energy consumption for iron and steel production

	Specific final energy consumption (GJ/tonne crude steel)[10]	**Estimated share of scrap input**[11]
Year	**2003**	**2004**
OECD Europe	9.0	47%
Transition economies	17.1	26%

---

[9] http://www.worldsteel.org/?action=stats&type=iron&period=year&year=2005
http://www.worldsteel.org/?action=stats&type=steel&period=year&year=2005

[10] Excluding process energy consumption (coke consumption ~6 GJ/tonne pig iron)

[11] Estimated based on pig iron and DRI for total steel production.

	Specific final energy consumption (GJ/tonne crude steel)[10]	**Estimated share of scrap input**[11]
Year	**2003**	**2004**
OECD North America	10.0	62%
Latin America	20.6	0%
Africa	16.9	24%
Middle East	2.8	7%
China	15.1	0%
South Asia	15.2	0%
East Asia	10.5	62%
OECD pacific	7.3	30%
World	***12.0***	***21%***

Sources: IISI statistical yearbook 2005[12] and IEA (2005)

The specific energy consumption differs per region, depending on energy efficiency of the iron and steel plants and the amount of scrap versus pig iron or DRI input. Table 7 shows best practice specific energy consumption for steel production.

Table 7 Best practice final energy consumption for iron and steel production (Worrell, 1999 and Phylipsen et al, 1998)

Product	**Specific energy consumption (GJ/t)**
Basic Oxygen Furnace – pig iron input	7[13]
Electric Arc Furnace – scrap input	2

The specific energy consumption for EAF steel from scrap input is lower than for BOF steel. Increasing the amount of recycled steel is therefore also an energy savings option.

We assume that with implementing the three measures described above together with increased recycling of steel, the specific final energy consumption for iron and steel production can be reduced to an average of 6 GJ/tonne crude steel by 2050 in all regions. This is based on 50% BOF steel and 50% EAF steel with scrap input and 1.5 GJ tonne crude steel for hot and cold rolling. For the Middle East we assume no

---

[12] http://www.worldsteel.org/?action=stats&type=iron&period=year&year=2005
http://www.worldsteel.org/?action=stats&type=steel&period=year&year=2005

[13] Including energy consumption blast furnace, excluding process energy consumption.

energy savings since specific energy consumption is already (too) low, possibly due to errors in the underlying data. For the Constraint scenario we assume that the specific final energy consumption can be reduced to 7.5 GJ/tonne crude steel.

Table 5 shows the share of final energy consumption by the iron and steel sector in total industry by region, for the year 2003. We assume that this share remains equal in the period 2003-2050.

Table 8 Share final energy consumption iron and steel sector in industry in base year 2003

	Industry - fuels	**Industry - electricity**	**Total industry**
OECD Europe	11%	12%	11%
OECD North America	6%	6%	6%
OECD Pacific	11%	17%	13%
China	23%	17%	22%
Latin America	16%	12%	15%
Africa	7%	11%	8%
Middle East	1%	4%	1%
Transition Economies	19%	22%	20%
East Asia	11%	0%	9%
South Asia	5%	8%	6%
World	***12%***	***12%***	***12%***

Source: IEA (2005)

Chemical industry

8. Membrane product separation

An important energy consuming step in the chemical industry is cryogenic, pressurized product separation. An alternative to this is separation by membranes. A membrane can be described as a selective barrier between two phases. This barrier is not equally permeable for different components. A driving force, e.g. a (partial) pressure difference, is applied over the membrane. The result is a separation of the feed stream into two streams: the stream that flows through the membrane (permeate) and the remaining stream (retentate). Unfortunately, membrane selectivity and permeability are often inversely related. Membranes can be used for both liquid and gas separation.

The use of membranes for product separation reduces compression energy requirements by 50% and separation energy requirements by 80% (Phylipsen et al, 1999). In total this corresponds to 35% of the overall energy consumption of an ethylene plant.
Although membranes are used for a number of products, like the recovery of hydrogen in refineries, it is not yet used for bulk chemicals. We assume that the use of membranes can reduce fuel consumption in the chemical industry by 35% in 2050. For the Constraint scenario we assume 20% in 2050.

Table 9 shows the share of fuel consumption by the chemical sector in fuel consumption for the total industry by region, for the year 2003. We assume that this share remains equal in the period 2003-2050.

Table 9 Share fuel consumption chemical sector in fuel consumption industry for base year 2003

	Industry - fuels
OECD Europe	19%
OECD North America	24%
OECD Pacific	13%
China	23%
Latin America	13%
Africa	3%
Middle East	33%
Transition Economies	18%
East Asia	12%
South Asia	13%
World	*19%*

Source: IEA (2005)

Other industries

9. Improved energy-efficiency other industries

We have specified specific measures for the aluminium industry, iron and steel and the chemical industry. Other important industries, are non-metallic minerals (e.g. cement and glass), paper and pulp, food and tobacco, machinery, textile and others. Together these industries account for 64% of the total energy demand of industries worldwide (see Figure 5).

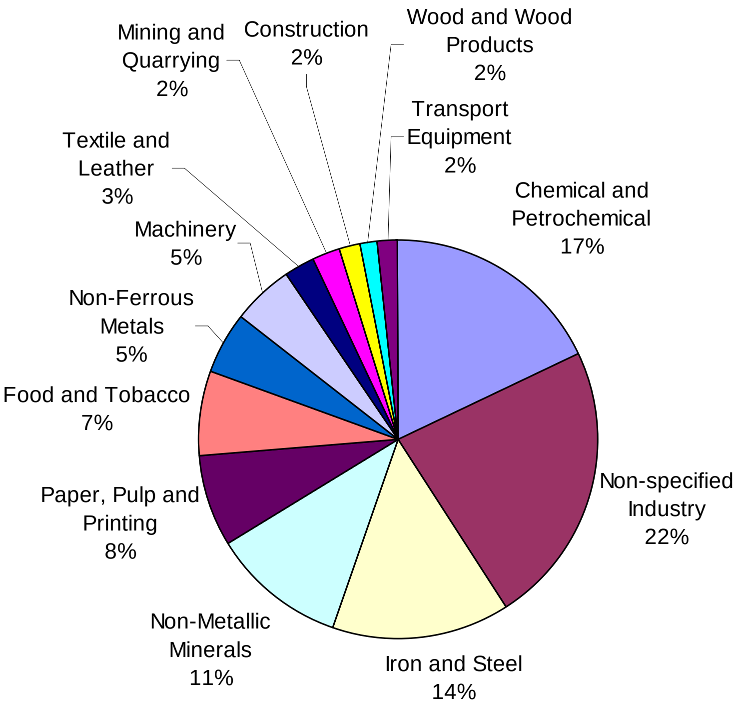

Figure 5 Final energy demand for industry by sector in 2003 worldwide

Additional to the horizontal measures that are defined (efficient motor systems, pinch analysis and improved process control), the energy-efficiency of the other industries can be further improved.

The opportunities for future energy-efficiency improvement for a number of industrial sectors was analysed by De Beer (1998). It was found that the energy demand could be reduced by more than 50% by the following measures:

- Using state-of-the-art processes
- More material-efficient product design
- Material and product recycling

A study by Blok (2005) showed that energy consumption for the pulp and paper industry could be reduced by 70% by applying best practice technologies. For ammonia production and nitric acid production the amounts were found to be 35% and 40%, respectively. For cement manufacturing the energy savings potential is estimated to be 75% (Sinton et al, 2002).

For the Ambitious scenario we assume the final energy demand in the other industries can be reduced by 50% in 2050. For the Constraint scenario we assume 30%.

3.3 Transport fuels

Figure 6 shows a breakdown of the final energy demand for transport in 2050.

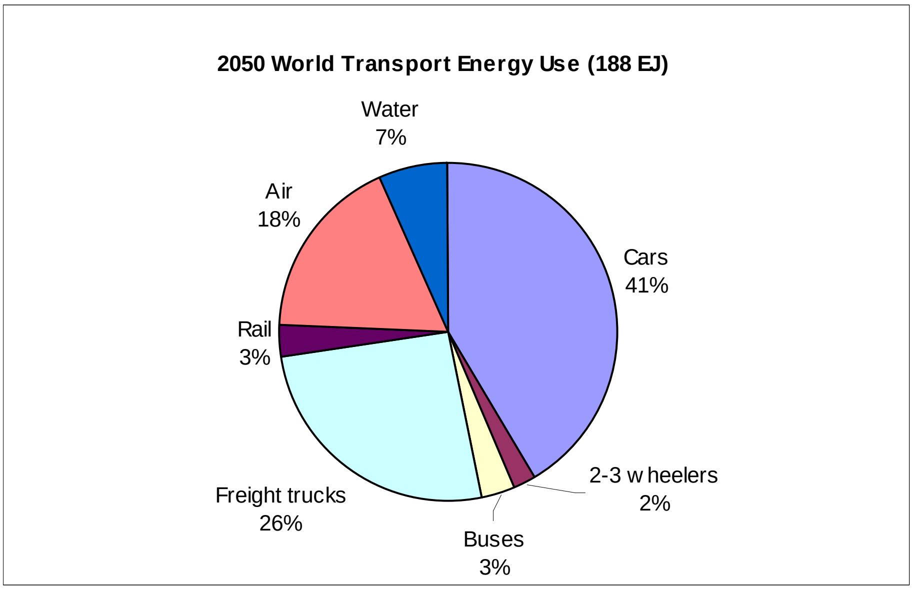

Figure 6 Breakdown of final energy demand for transport in 2050 (IEA/SMP, 2004)

Road transport represents more than 70% of the total energy demand for transport worldwide in 2050. In this study we look at reducing energy demand from passenger cars, freight trucks and buses because these sectors consume most energy.

Figure 7 shows the share of passenger cars, freight trucks and buses in total energy consumption for transport in 2050 by region.

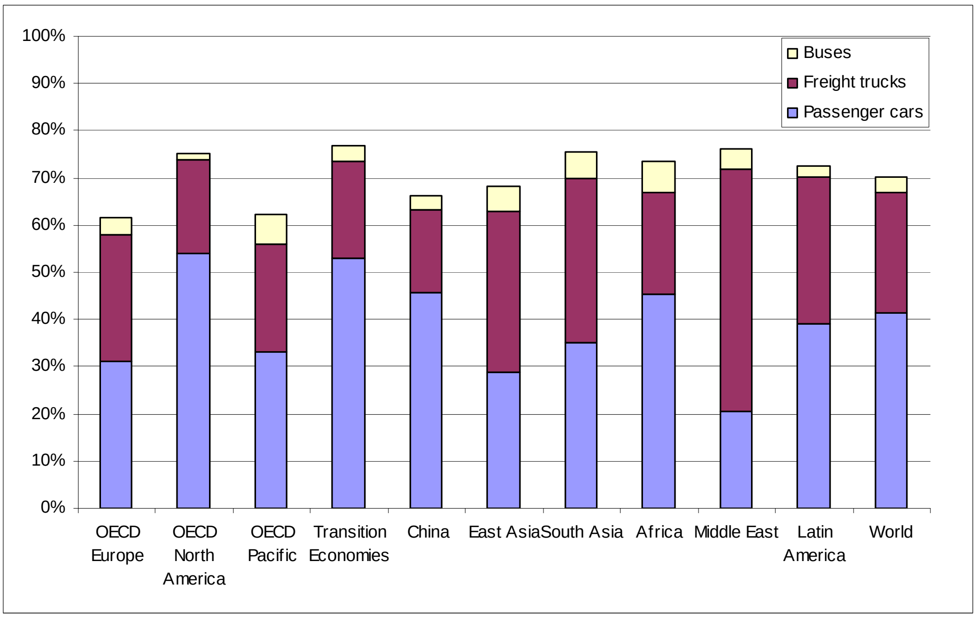

Figure 7 Passenger cars, freight trucks and buses in total energy consumption by transport in 2050 (IEA/SMP, 2004)

1. Efficient passenger cars

Many technologies can be used to improve the fuel efficiency of passenger cars. Examples are energy-efficiency improvements in engines, weight reduction and friction and drag reduction.

The impact of the various measures on fuel efficiency can be substantial. Hybrid vehicles, combining a conventional combustion engine with an electric engine, have relatively low fuel consumption. The most well-known is the Toyota Prius, which originally had a fuel efficiency of about 5 litre of gasoline-equivalent per 100 km (litre ge/100 km). Recently, Toyota presented an improved version with a lower fuel consumption of 4.3 litre ge/100 km. Further developments are underway as shown by the presentation of new concept cars by the main U.S. car manufacturers in 2000 with specific fuel use as low as 3 litre ge/100 km. There are suggestions that applying new light materials, in combination with the new propulsion technologies may bring fuel consumption levels down to 1 litre ge/100 km.

Table 10 shows an overview of best practice efficiencies now and in the future.

Table 10 Efficiency of cars and new developments (Blok, 2004)

	Fuel consumption (liter ge/100 km)	**Source**
Present average	10.5	IEA/SMP (2004)
Hybrids on the market (medium-sized cars)	~5 (1997) 4.3 (2003)	EPA (2003)
Improved hybrids or fuel cell cars (average car)	2 – 3	USCAR (2002) Weiss et al (2000)
Ultralights	0.8 - 1.6	Von Weizsäcker et al (1998)

For this analysis we assume that the average energy consumption of passenger cars can be reduced to 2 litre ge/100 km in 2050 for all regions. This can be achieved by continuous efforts in innovation, so that cars consuming 1.5 – 2.5 litre ge/100 km are on the market by 2030. For the energy savings potential in the Constraint scenario we assume 4 litre ge/100 km. This reflects the tendency toward increased sales of larger cars, that is currently visible in car markets in many countries. It is expected in the Constraint scenario that this trend continues further.

Table 11 shows the specific fuel consumption in litre per 100 km for passenger cars by region in 2000 and the estimated fuel consumption in 2050. The estimated energy savings from increasing the efficiency of passenger cars to 2 and 4 litre ge/100 km is indicated in the right-hand column.

Table 11 Specific fuel consumption by passenger cars in 2000 and estimate for 2050 (IEA/SMP, 2004)

Region	**Fuel consumption (liter ge/100 km)**		**Energy savings in 2050 (as % of energy use passenger cars)**	
	2000	*2050*	*Constraint*	*Ambitious*
OECD Europe	8.0	5.9	32%	66%
OECD North America	11.5	10.0	60%	80%
OECD Pacific	10.6	7.5	47%	73%
Transition Economies	10.3	8.4	52%	76%
China	11.4	8.5	53%	76%
East Asia	11.9	8.4	52%	76%

Region	Fuel consumption (liter ge/100 km)		Energy savings in 2050 (as % of energy use passenger cars)	
	2000	*2050*	*Constraint*	*Ambitious*
South Asia	11.2	8.2	51%	76%
Latin America	11.8	8.3	52%	76%
Africa	13.9	9.3	57%	78%
Middle East	12.0	8.3	52%	76%
World Average (stock-weighted)	10.5	8.5	53%	76%

2. Efficient freight vehicles

Table 12 shows average fuel consumption of diesel freight trucks by region.

Fuel consumption for hybrid trucks can be as low as 3 to 4 liter ge/100 tonne-km. For trucks with fuel cells, fuel consumption can be as low as 2 liter ge/100 tonne-km (IEA/SMP, 2004). For the Ambitious scenario we assume an energy intensity of 3 liter ge/ 100 tonne-km in 2050. For the Constraint scenario we assume 4 liter ge/ 100 tonne-km in 2050.

Table 12 Average energy intensity of diesel freight trucks (IEA/SMP, 2004)

Region	Fuel consumption (liter ge/ 100 tonne-km)		Energy savings in 2050 (as % of energy use freight trucks)	
	2000	*2050*	*Constraint*	*Ambitious*
OECD Europe	7.0	5.1	22%	41%
OECD North America	6.0	4.4	8%	31%
OECD Pacific	11.9	8.7	54%	66%
Transition Economies	10.3	6.6	39%	55%
China	11.2	7.2	45%	59%
East Asia	9.0	5.8	31%	48%
South Asia	10.4	6.7	41%	55%
Latin America	9.8	6.3	37%	53%
Africa	12.8	8.3	52%	64%
Middle East	12.0	7.7	48%	61%

3. Buses

The share of buses, including mini-buses, is for most regions small and ranges from 1% in OECD North America to 7% in Africa in 2050. The energy savings for buses are estimated to be similar to the energy savings possible for passenger cars although slightly more conservative; 60% for the Ambitious scenario and 40% for the Constraint scenario. Energy efficiency opportunities for buses are similar to those for cars e.g. hybrid buses and ultra light buses.

3.4 Other sectors

Figure 8 shows a breakdown of the final energy consumption of the sector "Others". The residential sector is the largest sector, consuming approximately 70% in 2003 worldwide, followed by the sector commercial and public services which consumes approximately 20% worldwide. In this study we only look at reducing energy demand in the residential sector and in the sector commercial and public services, because there are the sectors consuming most energy.

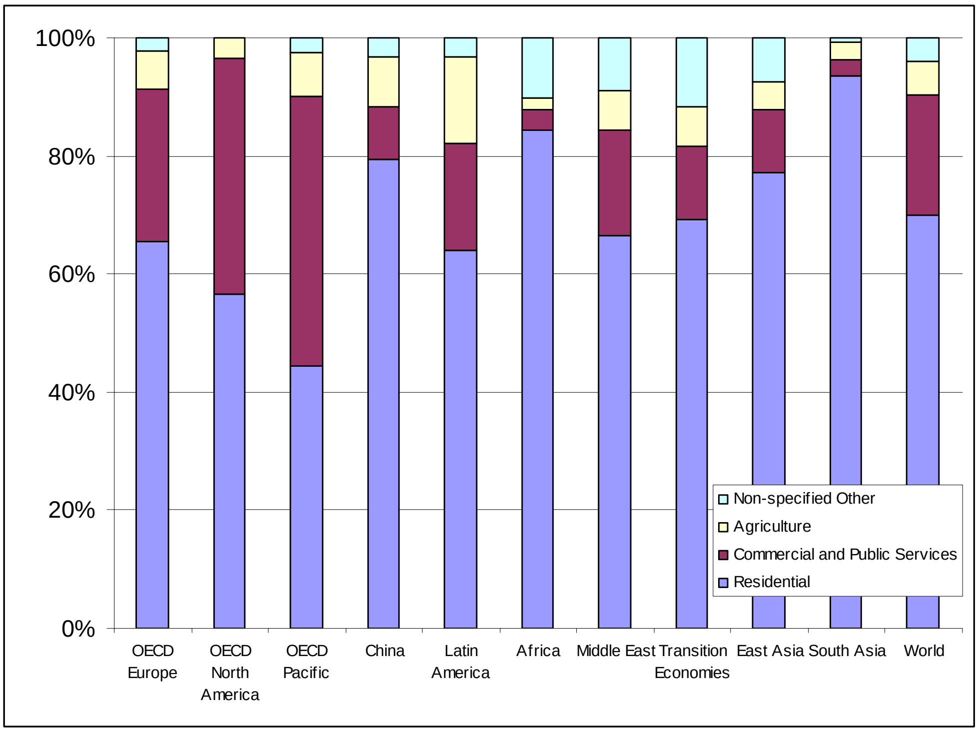

Figure 8 Breakdown of final energy consumption of the sector "Others"

1. Efficient appliances

Appliances in households include wet appliances like washing machines, dishwashers and clothes dryers, and brown appliances like TV and VCR, and refrigerators. Implementation of the current best practice can save approximately 30% on the average specific energy use of these appliances (Joosen and Blok, 2001). With advanced technologies energy consumption of these appliances can be reduced by 80% (Cicero, 1997).

Typical office-appliances are computers, monitors, printers and photocopiers. Office-appliances account for one of the fastest growing end-users of electricity in the service sector. Computers are responsible for the largest part of the electricity consumption. Electricity reduction can be achieved by power down management and efficient computer systems (LCD screens, laptops). The specific energy use of office-appliances can be reduced by 50% - 75% through a combination of power management and energy-efficient computer systems (Harmelink et al, 2003).

Blok (2005) shows that by increased efforts in innovation the energy consumption of appliances can be reduced by 75% in 50 years in comparison to baseline energy consumption.

For the Ambitious scenario we assume that the electricity consumption of appliances in households and services can be reduced by 75% in 2050. For the Constraint scenario we assume 50%. Appliances in services and households account for approximately 25% of the total electricity consumption of these sectors (WBCSD, 2005).

2. Efficient cooling

Introduction of current best practice cooling equipment could lead to a specific electricity reduction of approximately 40%, compared to the current average level. In case new techniques are used, such as vacuum insulation, specific energy savings by 80% can be achieved compared to the current average energy consumption (Harmelink, 2003).

The energy consumption for air conditioning has become significant in the services sector. Two tendencies are observed in the energy demand for cooling:

- Increase of the amount of equipment, causing higher cooling loads,
- Increased comfort demands, causing higher cooling loads.

When these tendencies are taken into consideration it is expected that there will be an increased demand for cooling. There are generally two ways for energy conservation in this area: reducing the need for cooling and improving the efficiency of the cooling system. We assume that the electricity consumption for cooling can be reduced by 60% in 2050 in comparison to reference energy demand. For the Constraint scenario we assume 30% in 2050 in comparison to reference energy demand. Cooling consists of approximately 15% of the electricity consumption in the services sector (WBCSD, 2005).

3. Efficient lighting

Lighting accounts for approximately one third of the electricity consumption in buildings (Munkejord, 2003). Energy savings options for lighting are e.g. Compact Fluorescent Lights (CFLs) and Light Emitting Diodes (LEDs). CFLs are essentially folded fluorescent tubes. Nowadays there is an extensive assortment in shape and fitting. A CFL uses 60%-80% less energy compared to a standard light bulb, producing the same amount of light (Harmelink et al, 2003). LEDs can be used for e.g. street lighting and reduce electricity consumption by 50%.

Electricity consumption for lighting can be further reduced by a lighting control system detecting occupancy of a room or operating daylight. This can reduce the amount of burning hours.

The savings potential of for lighting is estimated to be 50% from 2010 onwards. For the Constraint scenario we assume 30% from 2010 onwards.

4. Reduce stand-by losses

Several studies indicate that stand-by power losses are on average responsible for 5%-13% of the electricity use in households in OECD countries (Lebot et al, 2000). Replacement of existing appliances with those appliances having the lowest stand-by power losses would reduce standby power consumption by 70% (Harmelink et al, 2003). For the Constraint scenario we assume 50%. We assume that this measure can be implemented by 2010. The share of stand-by power losses is assumed to be 7% of the electricity consumption of households in 2050.

5. Improved heat insulation

Building design and heat insulation can save up to 80% of the average heat demand for buildings (Cicero, 1997 and Kaan and De Boer, 2006).

Figure 9 shows fuel consumption for the residential sector and commercial and public services per capita in 2003.

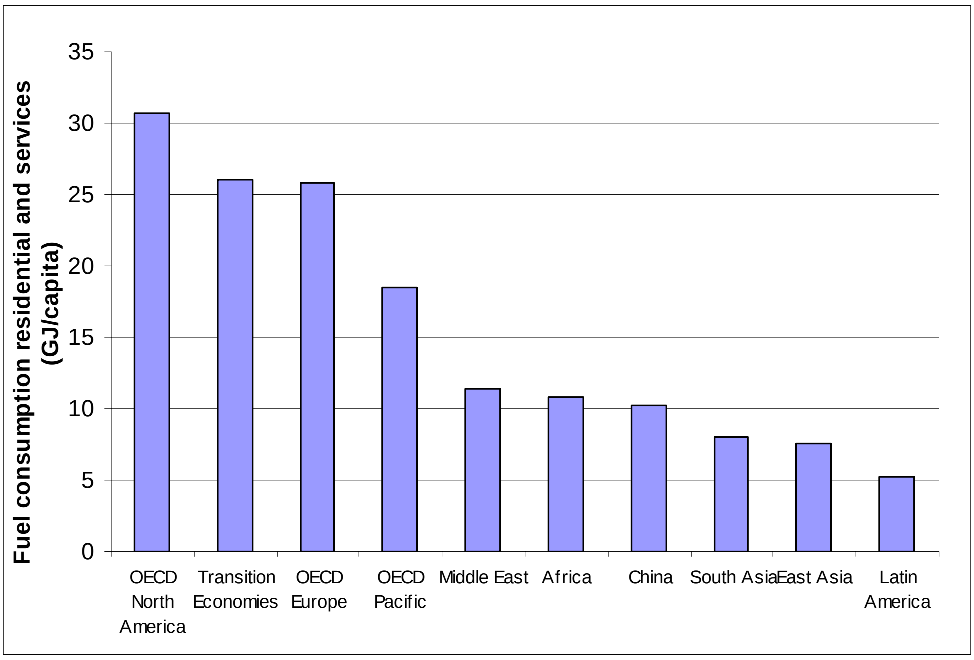

Figure 9 Fuel consumption in residential and commercial and public services in base year 2003 per capita (GJ/capita)

For the regions OECD North America, Transition Economies, OECD Europe and OECD pacific, we assume that in 2050, the heat demand for buildings can be reduced by 40%, with a linear implementation up to 2050. For the Constraint scenario we assume 20%.

For the regions Middle East, Africa, China, South Asia, East Asia and Latin America, we assume that in 2050, the heat demand for buildings can be reduced by 20%, with a linear implementation up to 2050. For the Constraint scenario we assume 10%. We assume a more conservative estimate for these regions because the fuel consumption per capita is relatively low. The energy savings potential for these regions may be higher.

We apply this measure to the fuel consumption for residential and commercial and public services.

6. Reduce electricity use during non-office hours

Offices are used approximately 2000 hours a year. In many cases, the electricity consumption outside of office hours can be reduced substantially. Often ventilators, computers, printers and faxes keep running or are in standby mode. In many cases a number of lights are kept on at night. The electricity consumption outside of office hours is estimated by Harmelink et al (2005) to be 25%. By a few simple measures this power consumption can be reduced by 90%.

7. Energy-efficiency improvement for agriculture and non-specified others

4-18% of the energy demand in the sector Others is used for agriculture and in the sub sector “non-specified others”. The energy demand mainly arises from electricity consumption for equipment and energy consumption in buildings. We assume that for these sub sectors similar energy savings can be realised as in households and services. For the Ambitious scenario we assume an energy savings potential of 50% in comparison to reference energy demand. For the Constraint scenario we assume an energy savings potential of 30% in comparison to reference energy demand.

4 Results

This chapter gives an overview of the low energy demand scenarios per region, starting with the scenarios for the world as a whole.

The scenarios are used in an upcoming report by DLR. In this study a mix between the Constraint scenario and the Ambitious scenarios is used. This is indicated by DLR Alternative Scenario.

4.1 World

The figure below shows the final energy demand (PJ) for the reference scenario and the Constraint and Ambitious scenario in the period 2003-2050. The energy savings resulting from the two scenarios is given per year in percentages in the table below.

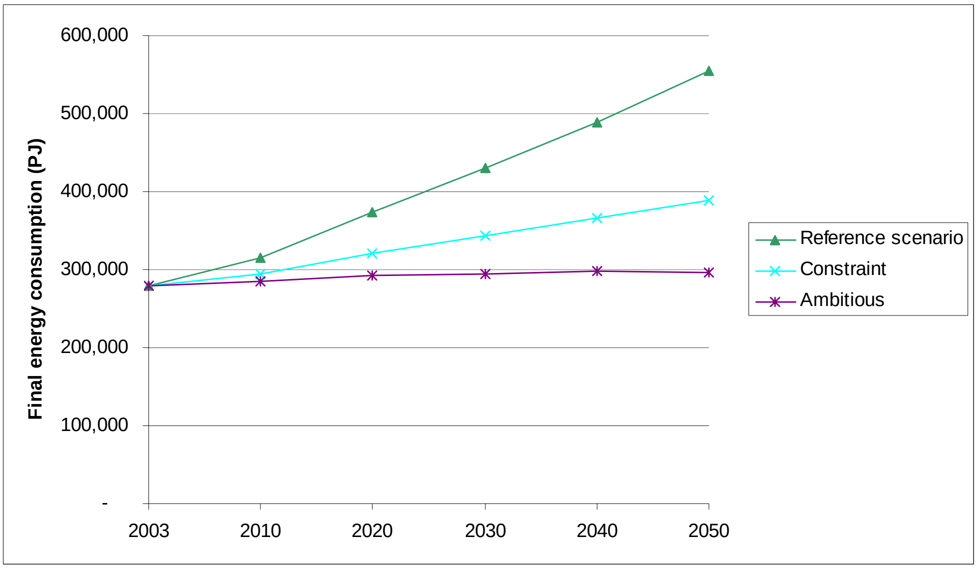

Figure 10 Reference scenarios and two low energy demand scenarios

Table 13 Energy savings in low energy demand scenarios in comparison to reference scenario

Energy savings (%)	**2003**	**2010**	**2020**	**2030**	**2040**	**2050**
Constraint scenario	0%	6%	14%	20%	25%	30%
Ambitious scenario	0%	10%	22%	32%	39%	47%
DLR Alternative Scenario	0%	8%	20%	29%	36%	42%

The two figures below show a breakdown of the energy savings by sector and by measure.

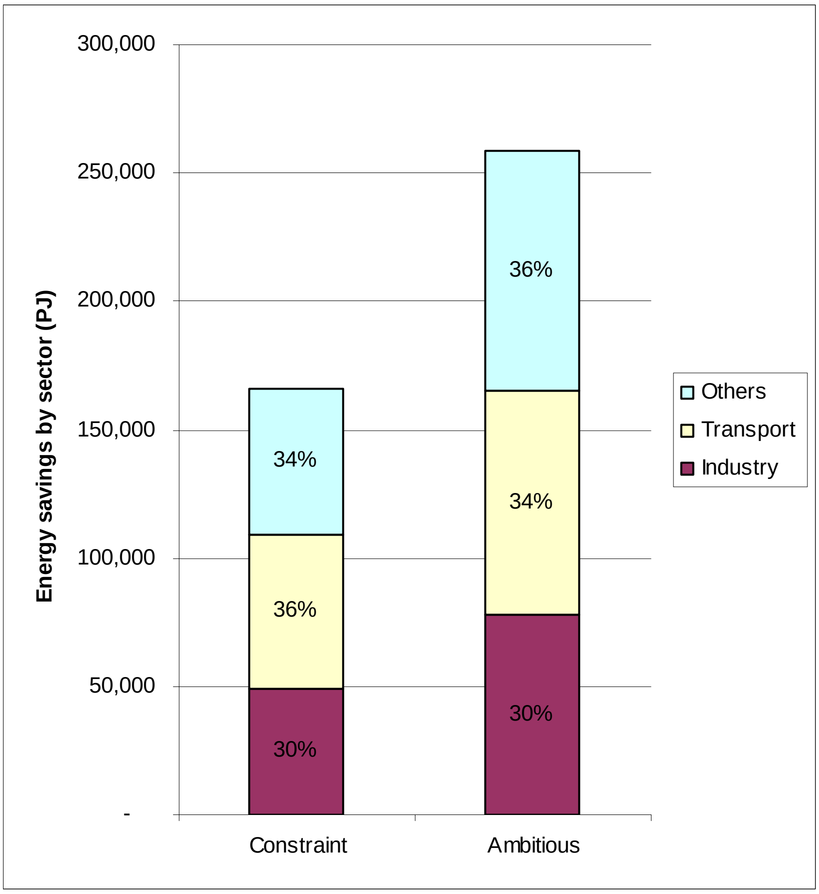

Figure 11 Energy savings per sector in 2050 for the two low energy demand scenarios

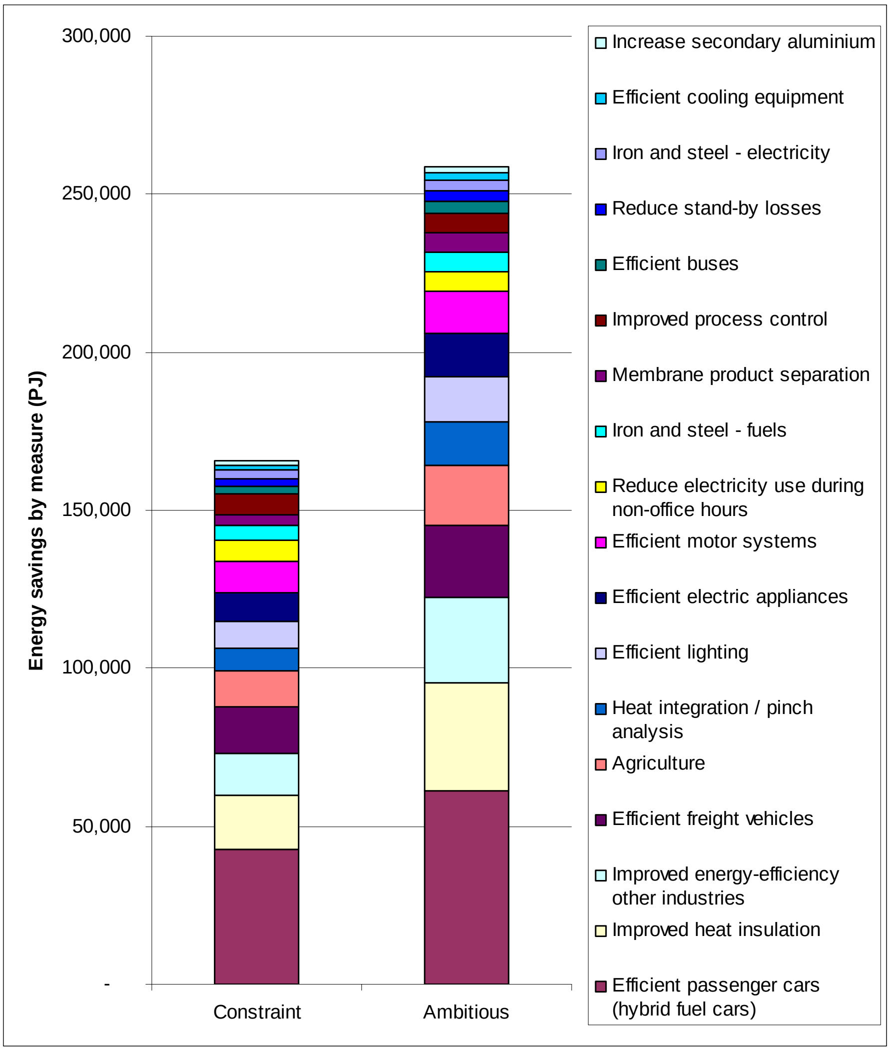

Figure 12 Energy savings per measure in 2050 for the two low energy demand scenarios

4.2 OECD North America

The figure below shows the final energy demand (PJ) for the reference scenario and the Constraint and Ambitious scenario in the period 2003-2050. The energy savings resulting from the two scenarios is given per year in percentages in the table below.

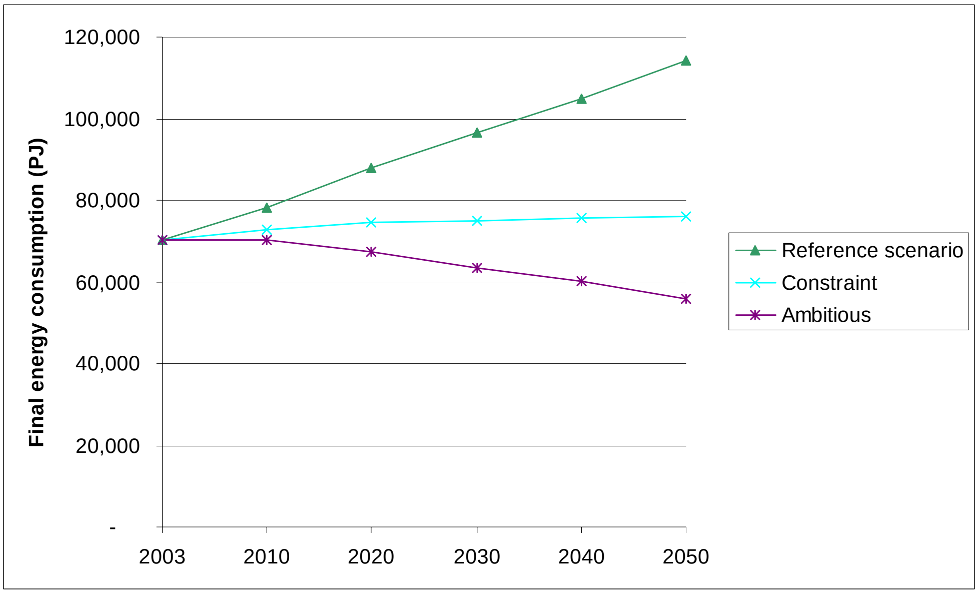

Figure 13 Reference scenarios and two low energy demand scenarios

Table 14 Energy savings in low energy demand scenarios in comparison to reference scenario

Energy savings (%)	2003	2010	2020	2030	2040	2050
Constraint scenario	0%	7%	15%	22%	28%	33%
Ambitious scenario	0%	10%	23%	34%	43%	51%
DLR Alternative Scenario	0%	9%	21%	31%	39%	47%

The figure below shows a breakdown of the energy savings by measure.

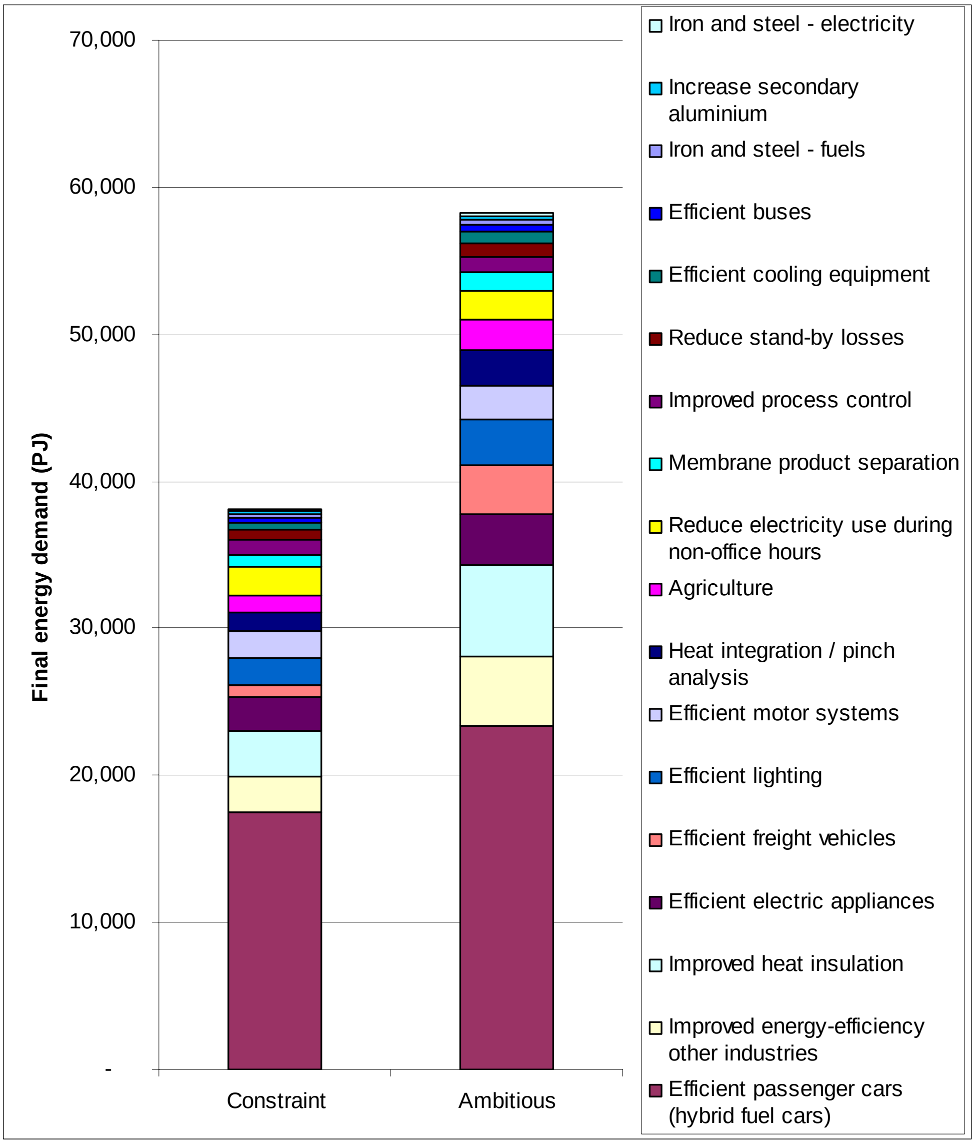

Figure 14 Energy savings per measure in 2050 for the two low energy demand scenarios

4.3 OECD Pacific

The figure below shows the final energy demand (PJ) for the reference scenario and the Constraint and Ambitious scenario in the period 2003-2050. The energy savings resulting from the two scenarios is given per year in percentages in the table below.

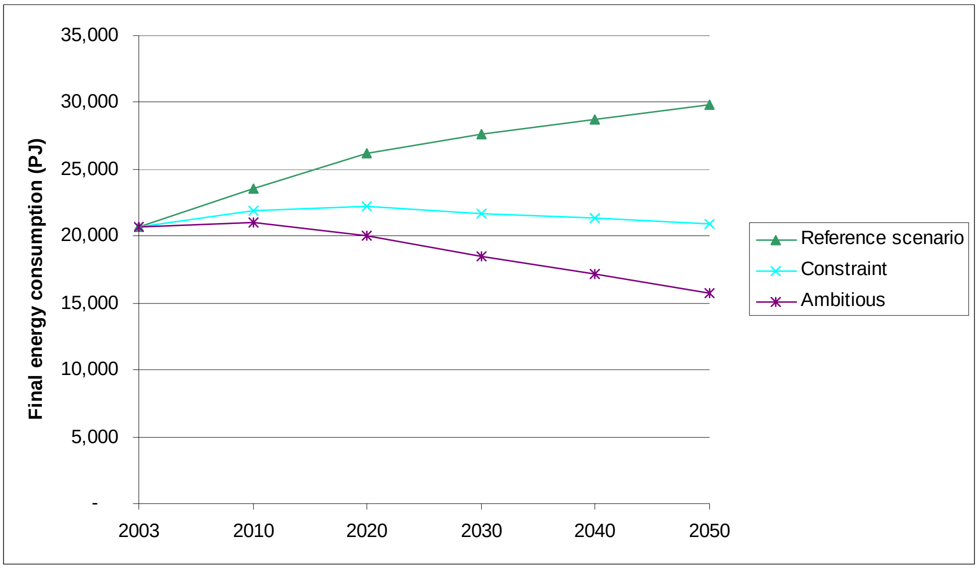

Figure 15 Reference scenarios and two low energy demand scenarios

Table 15 Energy savings in low energy demand scenarios in comparison to reference scenario

Energy savings (%)	2003	2010	2020	2030	2040	2050
Constraint scenario	0%	7%	15%	21%	26%	30%
Ambitious scenario	0%	11%	23%	33%	40%	47%
DLR Alternative Scenario	0%	9%	20%	29%	36%	42%

The figure below shows a breakdown of the energy savings by measure.

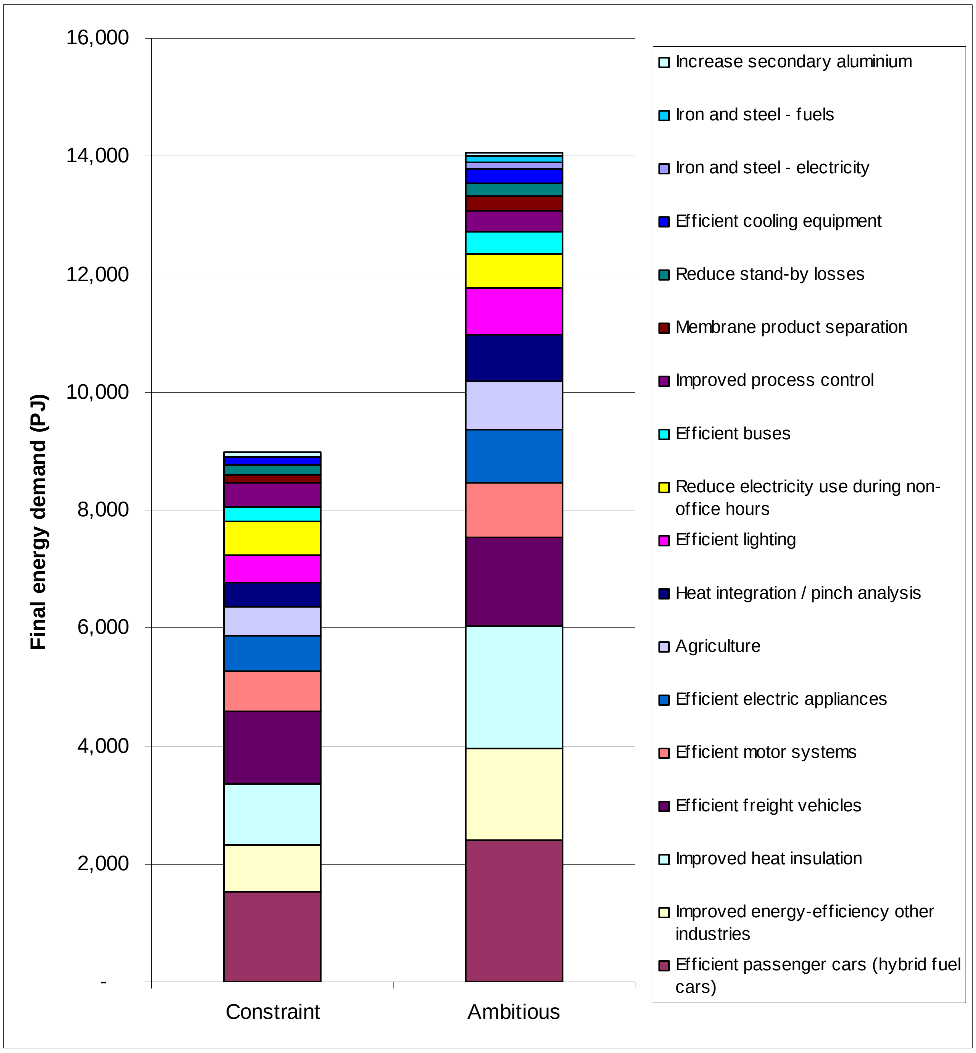

Figure 16 Energy savings per measure in 2050 for the two low energy demand scenarios

4.4 OECD Europe

The figure below shows the final energy demand (PJ) for the reference scenario and the Constraint and Ambitious scenario in the period 2003-2050. The energy savings resulting from the two scenarios is given per year in percentages in the table below.

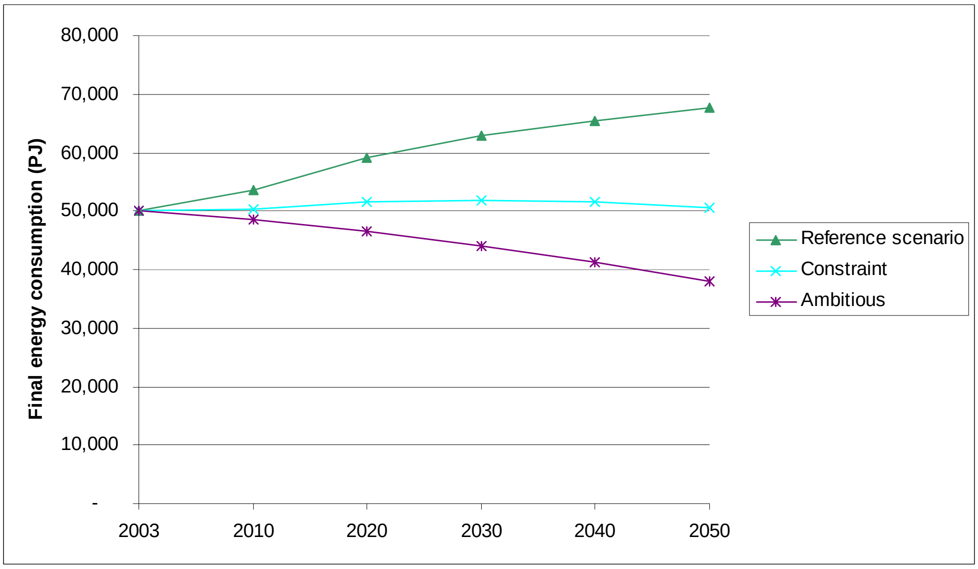

Figure 17 Reference scenarios and two low energy demand scenarios

Table 16 Energy savings in low energy demand scenarios in comparison to reference scenario

Energy savings (%)	2003	2010	2020	2030	2040	2050
Constraint scenario	0%	6%	13%	18%	21%	25%
Ambitious scenario	0%	9%	21%	30%	37%	44%
DLR Alternative Scenario	0%	8%	19%	27%	33%	40%

The figure below shows a breakdown of the energy savings by measure.

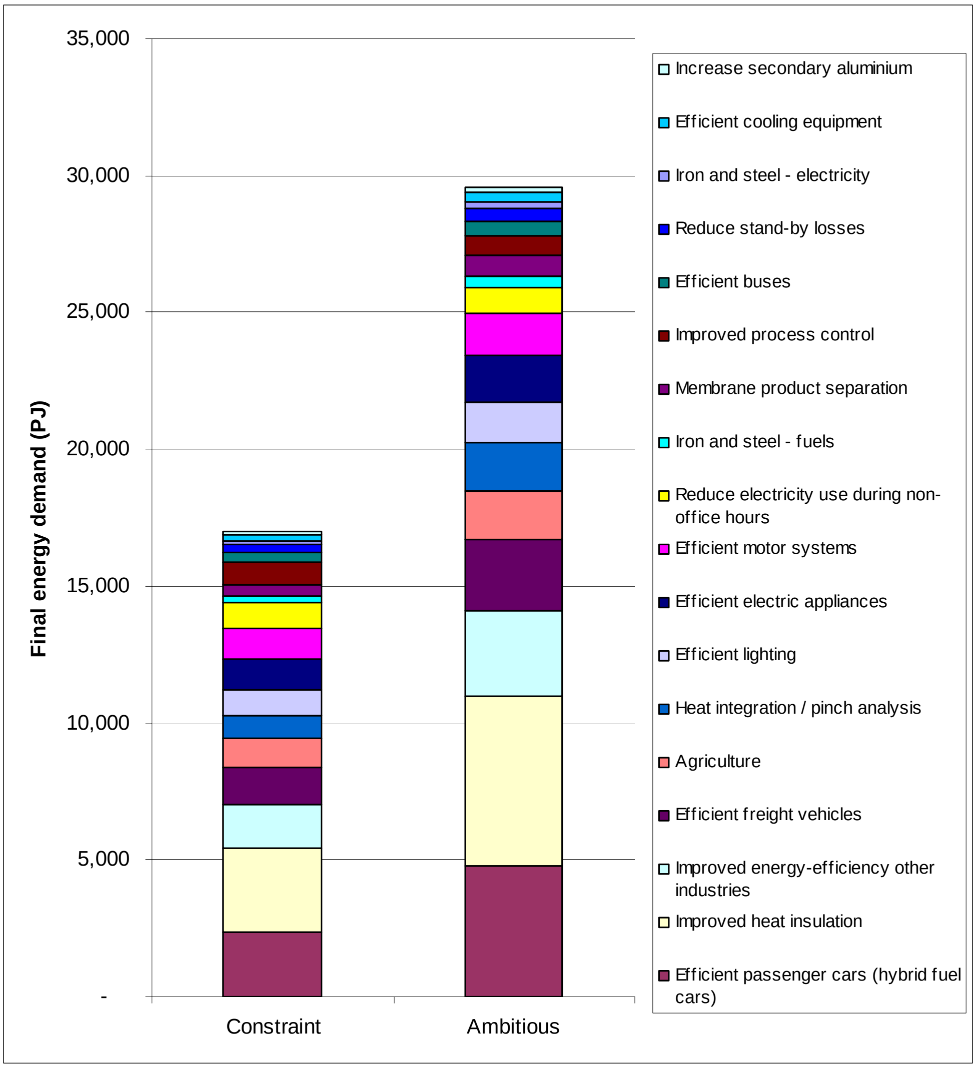

Figure 18 Energy savings per measure in 2050 for the two low energy demand scenarios

4.5 Transition Economies

The figure below shows the final energy demand (PJ) for the reference scenario and the Constraint and Ambitious scenario in the period 2003-2050. The energy savings resulting from the two scenarios is given per year in percentages in the table below.

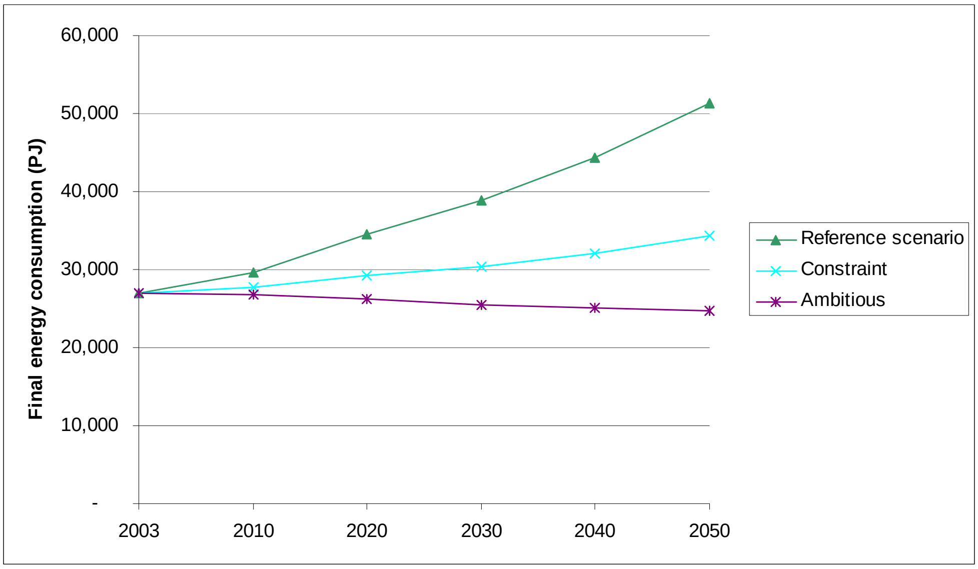

Figure 19 Reference scenarios and two low energy demand scenarios

Table 17 Energy savings in low energy demand scenarios in comparison to reference scenario

Energy savings (%)	**2003**	**2010**	**2020**	**2030**	**2040**	**2050**
Constraint scenario	0%	7%	15%	22%	27%	33%
Ambitious scenario	0%	10%	24%	35%	43%	52%
DLR Alternative Scenario	0%	9%	23%	33%	41%	49%

The figure below shows a breakdown of the energy savings by measure.

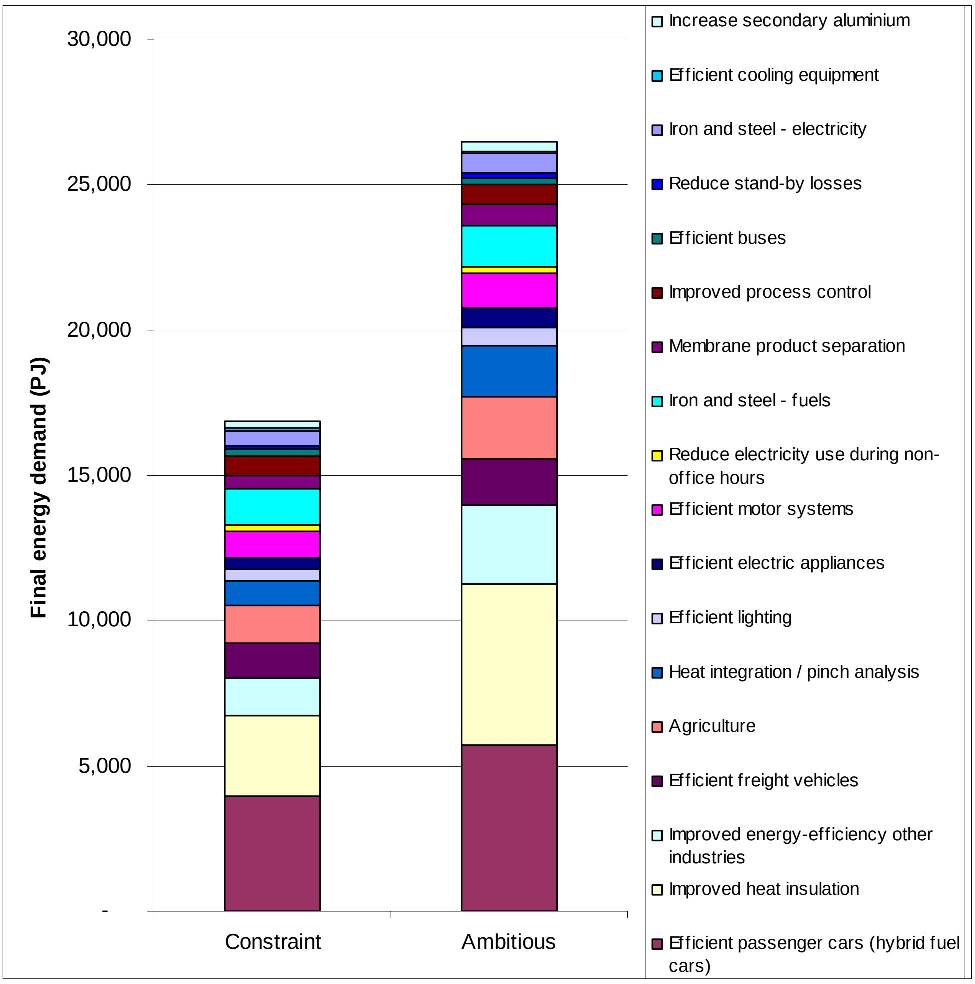

Figure 20 Energy savings per measure in 2050 for the two low energy demand scenarios

4.6 China

The figure below shows the final energy demand (PJ) for the reference scenario and the Constraint and Ambitious scenario in the period 2003-2050. The energy savings resulting from the two scenarios is given per year in percentages in the table below.

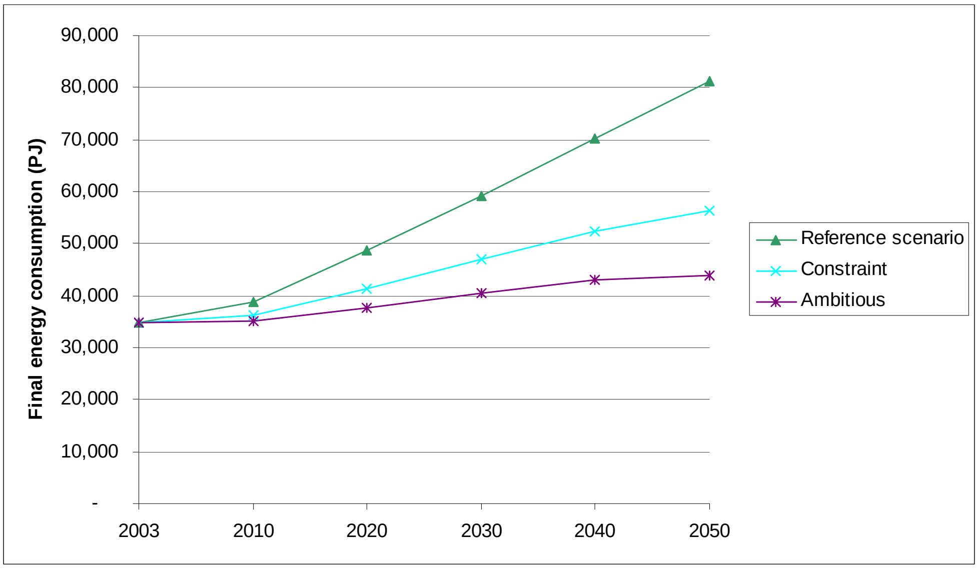

Figure 21 Reference scenarios and two low energy demand scenarios

Table 18 Energy savings in low energy demand scenarios in comparison to reference scenario

Energy savings (%)	**2003**	**2010**	**2020**	**2030**	**2040**	**2050**
Constraint scenario	0%	7%	15%	21%	26%	31%
Ambitious scenario	0%	10%	22%	32%	39%	46%
DLR Alternative Scenario	0%	9%	20%	28%	35%	41%

The figure below shows a breakdown of the energy savings by measure.

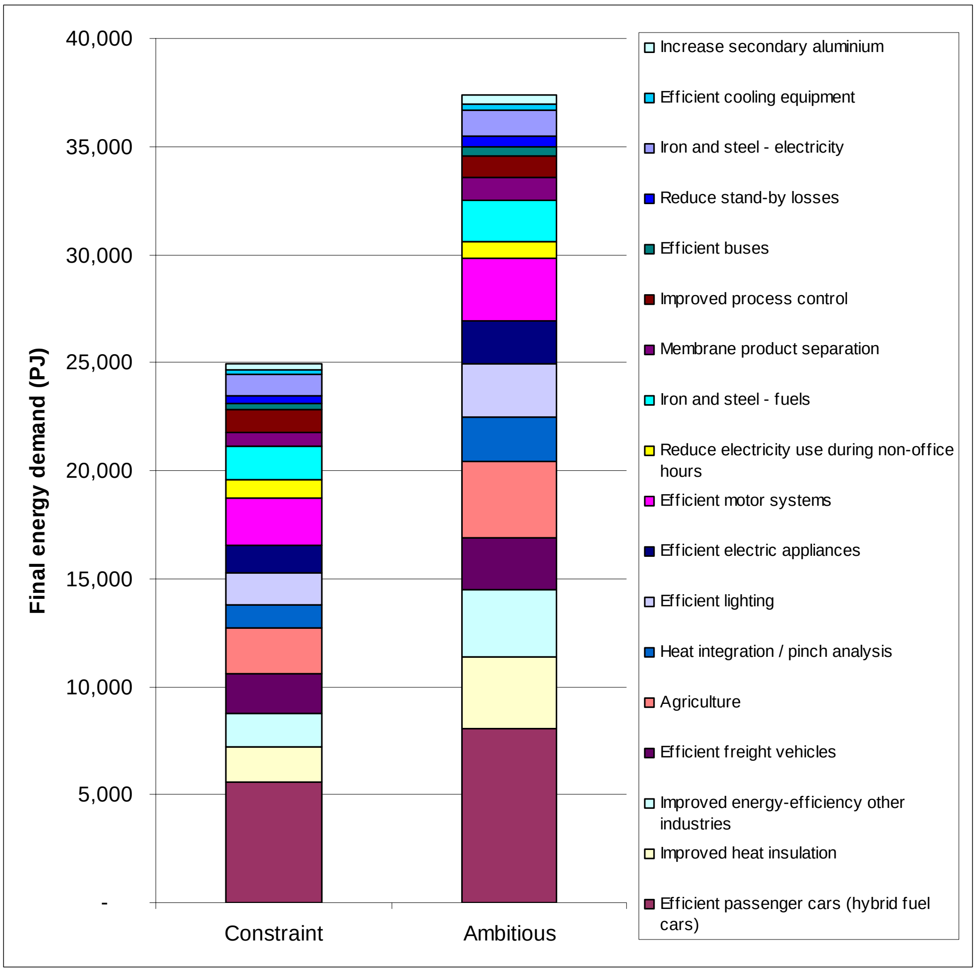

Figure 22 Energy savings per measure in 2050 for the two low energy demand scenarios

4.7 East Asia

The figure below shows the final energy demand (PJ) for the reference scenario and the Constraint and Ambitious scenario in the period 2003-2050. The energy savings resulting from the two scenarios is given per year in percentages in the table below.

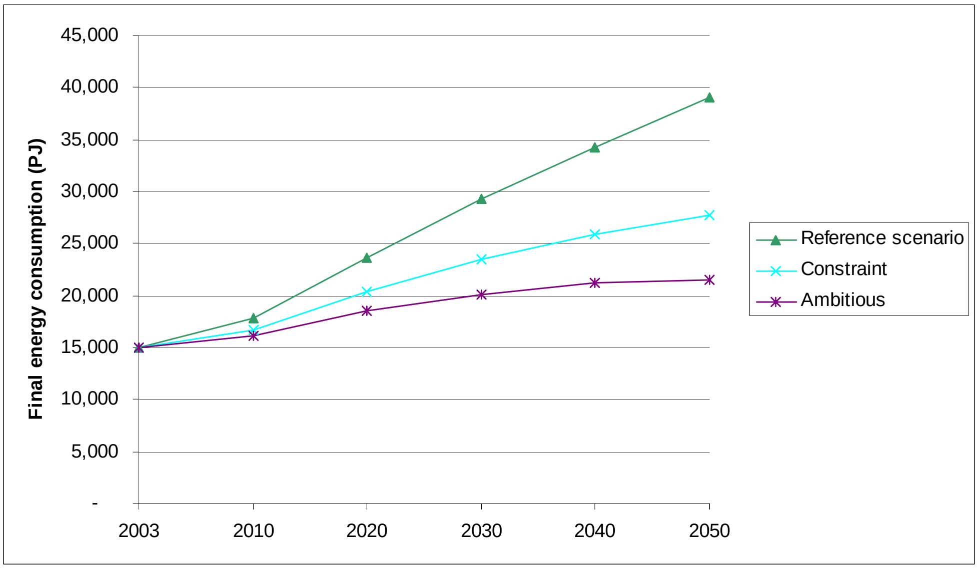

Figure 23 Reference scenarios and two low energy demand scenarios

Table 19 Energy savings in low energy demand scenarios in comparison to reference scenario

Energy savings (%)	**2003**	**2010**	**2020**	**2030**	**2040**	**2050**
Constraint scenario	0%	7%	14%	20%	24%	29%
Ambitious scenario	0%	10%	22%	31%	38%	45%
DLR Alternative Scenario	0%	9%	20%	28%	34%	40%

The figure below shows a breakdown of the energy savings by measure.

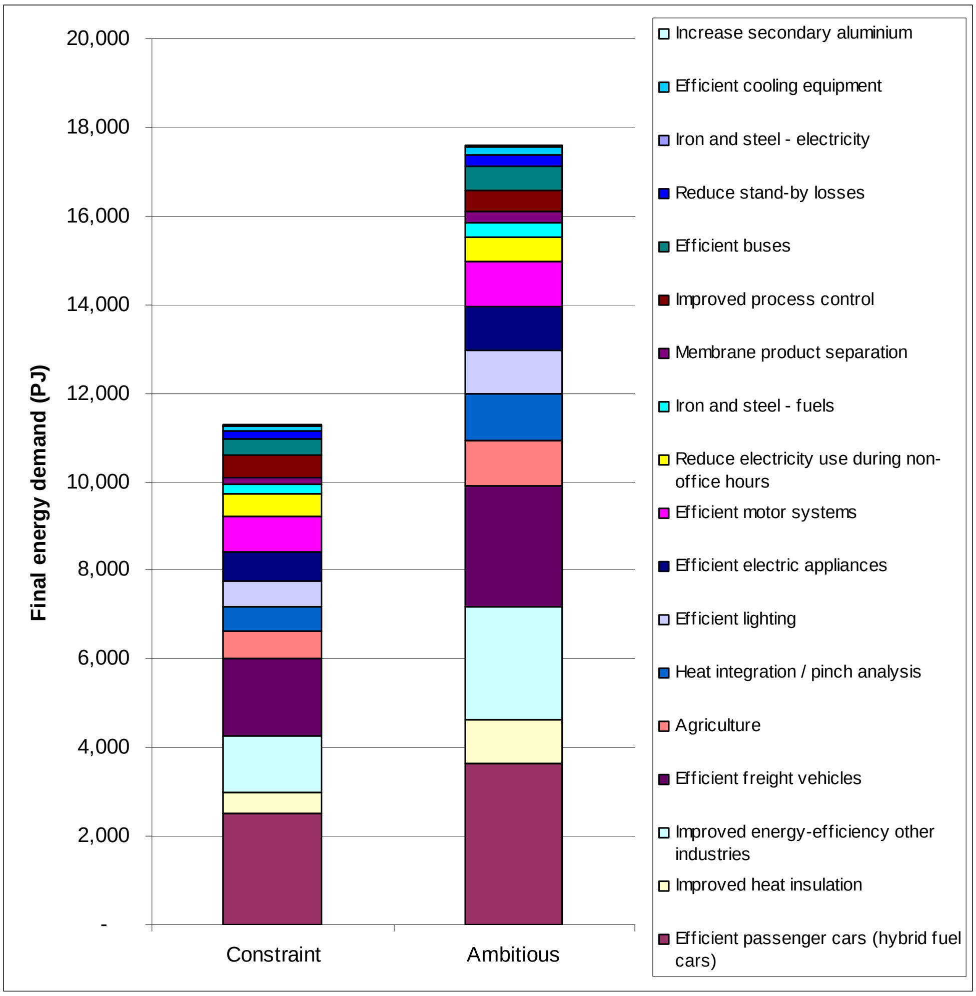

Figure 24 Energy savings per measure in 2050 for the two low energy demand scenarios

4.8 South Asia

The figure below shows the final energy demand (PJ) for the reference scenario and the Constraint and Ambitious scenario in the period 2003-2050. The energy savings resulting from the two scenarios is given per year in percentages in the table below.

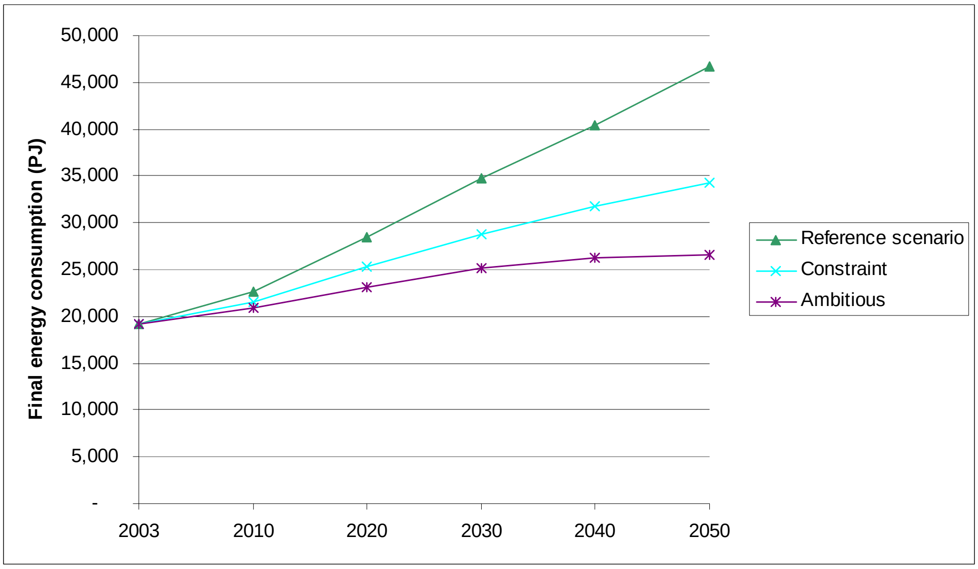

Figure 25 Reference scenarios and two low energy demand scenarios

Table 20 Energy savings in low energy demand scenarios in comparison to reference scenario

Energy savings (%)	**2003**	**2010**	**2020**	**2030**	**2040**	**2050**
Constraint scenario	0%	5%	12%	17%	22%	27%
Ambitious scenario	0%	8%	19%	28%	35%	43%
DLR Alternative Scenario	0%	7%	18%	26%	32%	39%

The figure below shows a breakdown of the energy savings by measure.

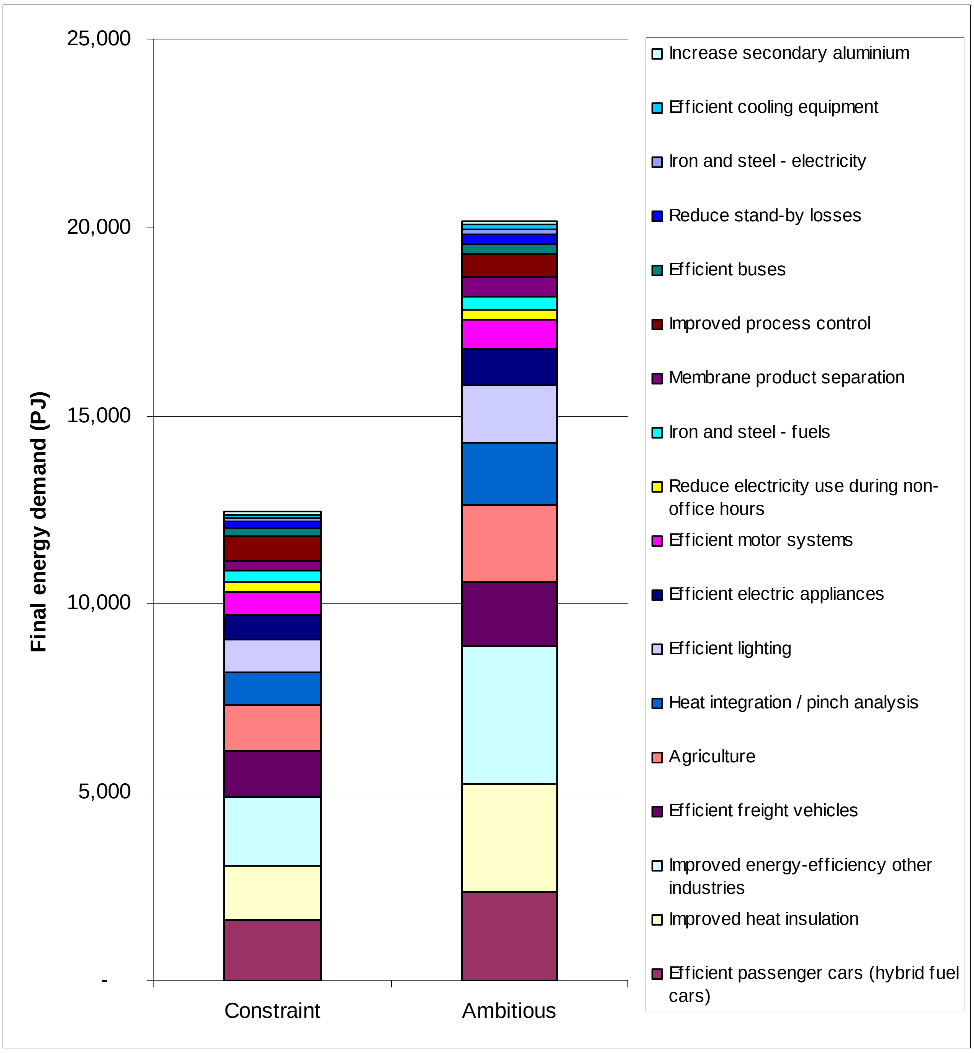

Figure 26 Energy savings per measure in 2050 for the two low energy demand scenarios

4.9 Middle East

The figure below shows the final energy demand (PJ) for the reference scenario and the Constraint and Ambitious scenario in the period 2003-2050. The energy savings resulting from the two scenarios is given per year in percentages in the table below.

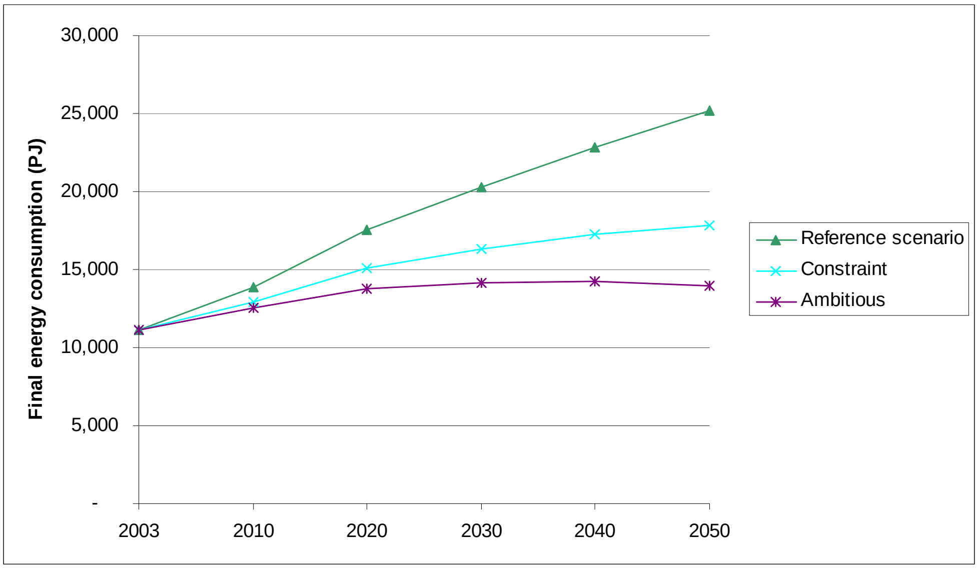

Figure 27 Reference scenarios and two low energy demand scenarios

Table 21 Energy savings in low energy demand scenarios in comparison to reference scenario

Energy savings (%)	2003	2010	2020	2030	2040	2050
Constraint scenario	0%	6%	14%	20%	24%	29%
Ambitious scenario	0%	9%	21%	30%	37%	45%
DLR Alternative Scenario	0%	8%	20%	28%	34%	41%

The figure below shows a breakdown of the energy savings by measure.

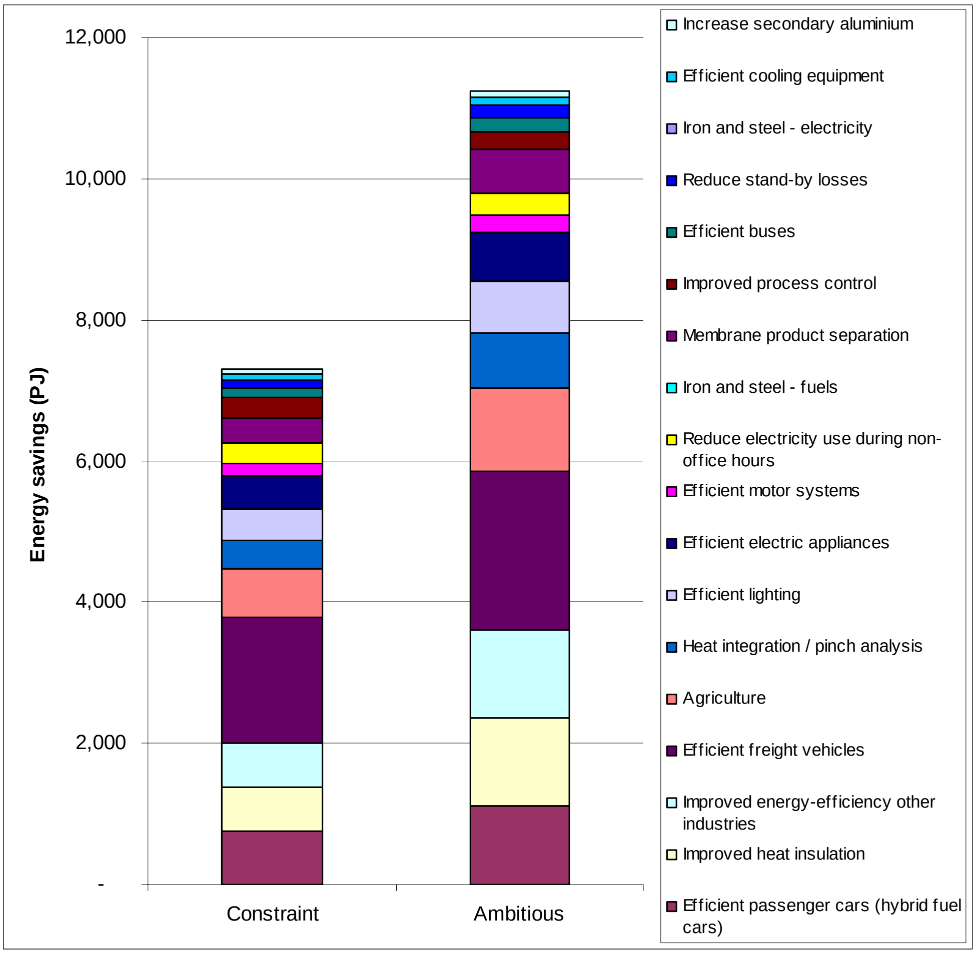

Figure 28 Energy savings per measure in 2050 for the two low energy demand scenarios

4.10 Latin America

The figure below shows the final energy demand (PJ) for the reference scenario and the Constraint and Ambitious scenario in the period 2003-2050. The energy savings resulting from the two scenarios is given per year in percentages in the table below.

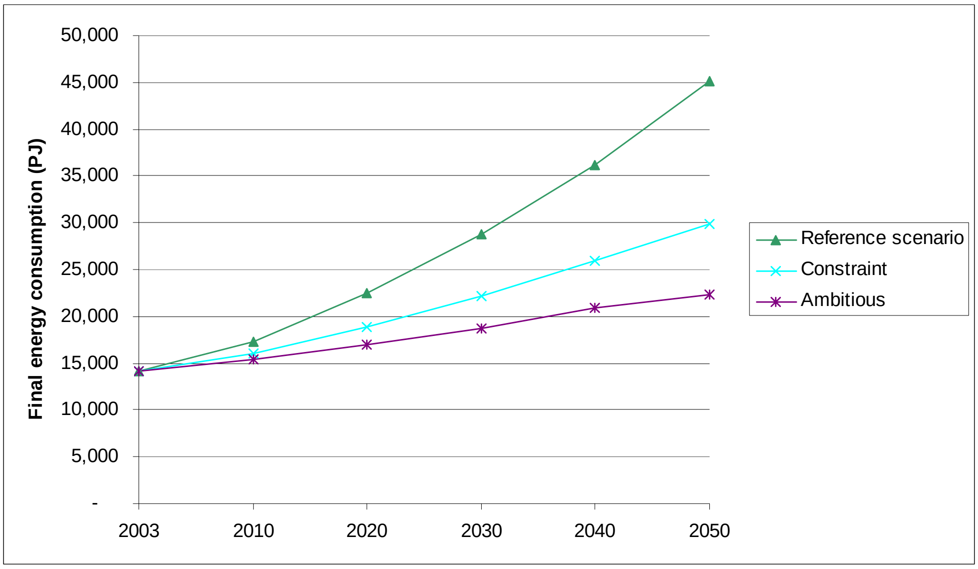

Figure 29 Reference scenarios and two low energy demand scenarios

Table 22 Energy savings in low energy demand scenarios in comparison to reference scenario

Energy savings (%)	2003	2010	2020	2030	2040	2050
Constraint scenario	0%	8%	16%	23%	28%	34%
Ambitious scenario	0%	11%	25%	35%	42%	50%
DLR Alternative Scenario	0%	10%	22%	31%	39%	46%

The figure below shows a breakdown of the energy savings by measure.

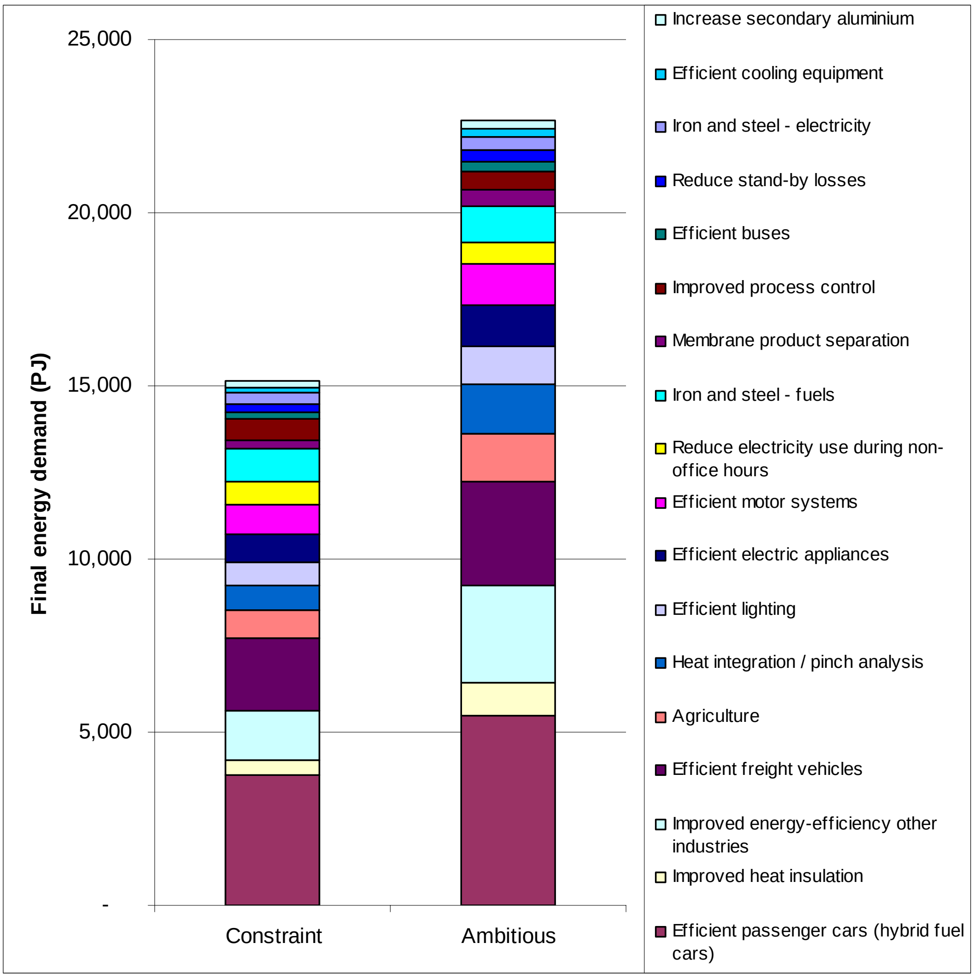

Figure 30 Energy savings per measure in 2050 for the two low energy demand scenarios

4.11 Africa

The figure below shows the final energy demand (PJ) for the reference scenario and the Constraint and Ambitious scenario in the period 2003-2050. The energy savings resulting from the two scenarios is given per year in percentages in the table below.

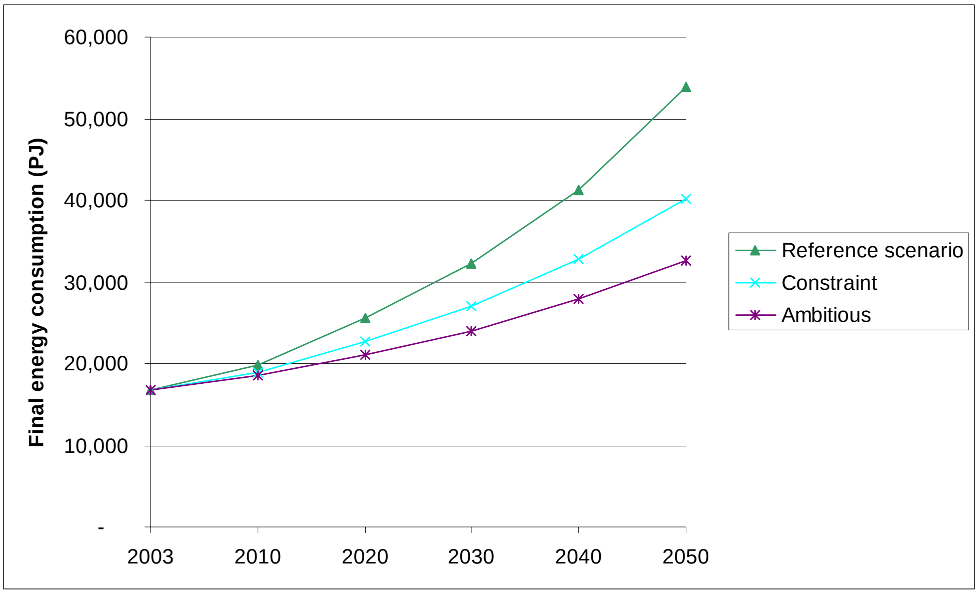

Figure 31 Reference scenarios and two low energy demand scenarios

Table 23 Energy savings in low energy demand scenarios in comparison to reference scenario

Energy savings (%)	**2003**	**2010**	**2020**	**2030**	**2040**	**2050**
Constraint scenario	0%	5%	11%	16%	21%	25%
Ambitious scenario	0%	7%	17%	25%	32%	40%
DLR Alternative Scenario	0%	6%	16%	24%	30%	36%

The figure below shows a breakdown of the energy savings by measure.

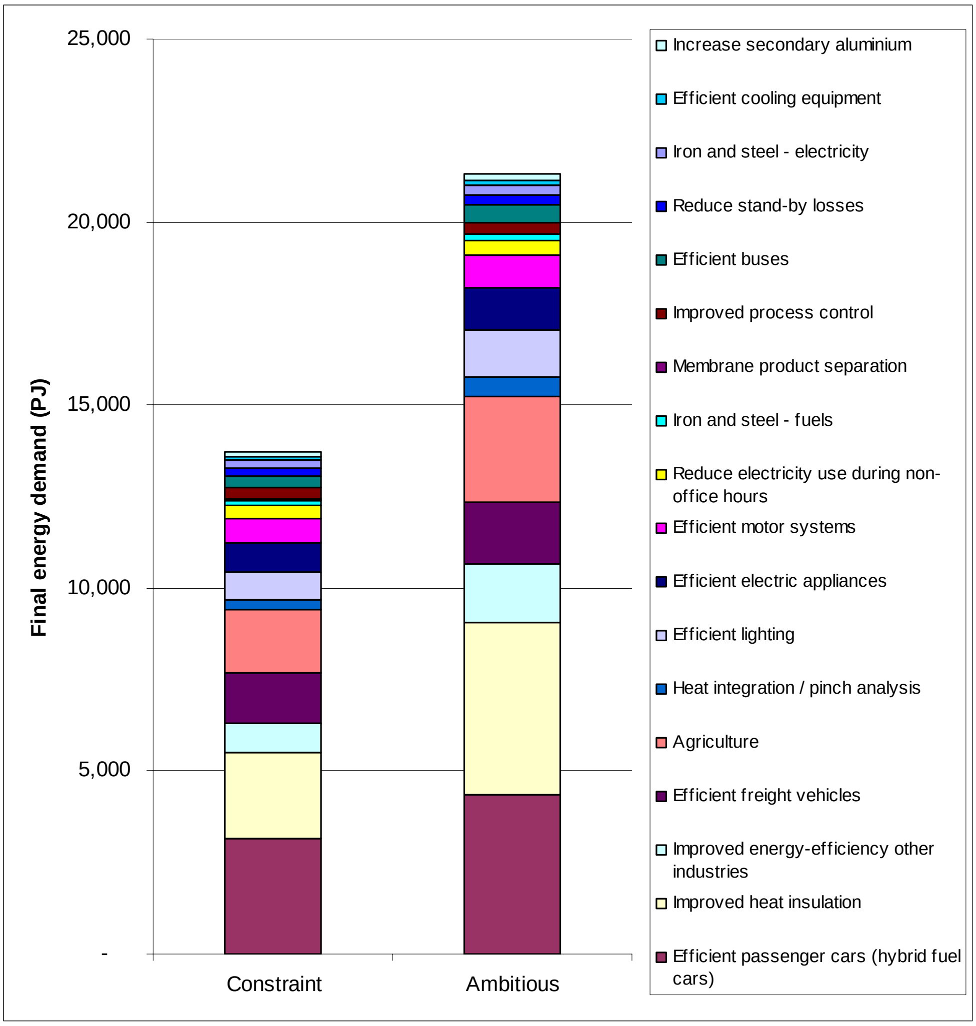

Figure 32 Energy savings per measure in 2050 for the two low energy demand scenarios

5 Conclusions

In this study we developed two low energy demand scenarios for the period 2003 to 2050 on a regional level. One is the Ambitious scenario, which is an ambitious energy efficiency scenario focusing on current best practice technologies and continuous efforts in innovation. The second scenario is the Constraint scenario with more moderate energy savings taking into account implementation constraints of technologies in terms of costs and other barriers.

In the Ambitious scenario the worldwide final energy demand reduces by 47% in 2050 in comparison to the reference energy demand. In the Constraint scenario the energy demand reduces by 30% in 2050. The resulting worldwide final energy demand is 295 EJ in 2050 in the Ambitious scenario and 388 EJ in the Constraint scenario. The reference final energy demand in 2050 is 554 EJ and the energy demand in the base year 2003 is 279 EJ worldwide.

The energy savings are fairly equal distributed over the three sectors industry (30% of savings), transport (34% of savings) and others (36% of savings). The most important energy savings options are efficient passenger and freight transport and improved heat insulation and buildings design, together accounting for 46% of the energy savings in the Ambitious scenario worldwide.

The energy savings per region in the Ambitious scenario range from 40% for Africa to 51% for OECD North America in 2050. In the Constraint scenario the energy savings range from 25% for Africa to 33% for OECD North America in 2050.

References

- Annibal T. de Almeida, P Fonseca, F Ferreira (1999). Carbon Saving Potential of Enery-Efficient Motor Technologies in Central and Eastern Europe. Paper presented at the IEA International Workshop on Technologies to Reduce Greenhouse Gas Emissions. 5-7 May Washington, USA
- Blok, K. (2004). Improving energy efficiency by 5% and more per year? Copernicus Institute. Utrecht University. The Netherlands.
- Blok, K. (2005). Improving energy efficiency by five percent and more per year? Journal of Industrial Ecology. Volume 8, Number 4. Massachusetts Institute of Technology and Yale University.
- Brandsma, R., W. Graus, C. Hendriks and K. Blok (2005). A low carbon futures tool. Phase 1: test for four countries. Assignment for Ministry of VROM (Netherlands Ministry of Housing, Spatial Planning and the Environment). Ecofys, Utrecht, The Netherlands.
- Cicero (1997). Towards a sustainable energy system – a long term transition strategy. Report 1997: 6. University of Oslo, Norway.
- De Beer, J.G., M.T. van Wees, E. Worrell and K. Blok (1994). ICARUS 3 - The Potential for Energy Efficiency Improvement in the Netherlands up to 2000 and 2015, Department of Science, Technology and Society, Utrecht University.
- De Beer, J. (1998). Potential for industrial energy-efficiency improvement in the long term. Ph.D. thesis, Utrecht University, Utrecht, the Netherlands.
- EC (1999). VSDs for Electric Motor Systems. SAVE study
- Ecofys (2001). Data on greenhouse gas emission reduction options for 2010 for the Member States of the European Union. Data reported in: C.A. Hendriks, D. de Jager, K. Blok et al. Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change: Bottom-up Analysis of Emission Reduction Potentials and Costs for Greenhouse Gases in the EU, Ecofys Energy and Environment and AEA Technology, Utrecht, The Netherlands, January 2001.
- Ecofys (2003). Low Carbon Electricity Systems. Methodology and results for the EU. Ecofys, Utrecht , the Netherlands. Prepared for WWF

- EPA (2003). Fuel Economy Guide, Model Year 2004, U.S. Environmental Protection Agency, Washington (www.fueleconomy.gov, accessed January 2004). USA
- Harmelink, M., K. Blok, M. Chang, W. Graus and S. Joosen (2005). Opportunities for acceleration of energy savings in the Netherlands. Ecofys, Utrecht, The Netherlands. Commissioned by Dutch Ministry of Economic Affairs.
- Harmelink, M., M. Voogt, W. Graus (2003). Low Carbon Electricity Systems. Methodology and results for the EU. Ecofys, Utrecht, the Netherlands. Prepared for WWF.
- Hydrocarbon Processing (HCP). 2001. Advanced Control and Information Systems 2001. Hydrocarbon Processing 9 80 pp.73-159 (September 2001).
- IEA (2004). World Energy Outlook. International Energy Agency. Paris, France.
- IEA (2004b). Oil crises & climate challenges. 30 years of energy sue in IEA coun-tries. International Energy Agency, Paris, France.
- IEA (2005). Energy Balances 2005. International Energy Agency. Paris, France.
- IEA/SMP (2004). IEA/SMP Model Documentation and Reference Case Projection. L. Fulton (IEA) and G. Eads (CRA) for WBCSD’s Sustainable Mobility Project (SMP), July 2004.
- Joosen S, K. Blok (2001). Economic Evaluation of Sectoral Emission Reduction Objectives for Climate Change. Economic Evaluation of Carbon Dioxide Emission Reduction in the Household and Services Sectors in the EU. Ecofys Energy and Environment, AEA Technology Environment and National Technical University of Athens.
- Kaan, H.F. and B.J. de Boer (2006). Passive houses: achievable concepts for low CO2 housing. ECN, Petten, The Netherlands.
- Keulenaar et al. (2004). Energy efficiency motor systems. European Copper Institute.
- Krewitt, W. and S. Kronshage (2006). Global Energy Scenario. Working paper. 21 March 2006. DLR, Institut für Technische Thermodynamik, Stuttgart, Germany.
- Kumana, J. (2000). The Pinch Analysis. http://www.oilandgasnewsworldwide.com/bkArticlesF.asp?Article=17610&Section=2463&IssueID=382

- Lebot B, A Meier, A Angelade (2000). Global Implication of Stand-by Power Use. IEA, France, LBNL, USA, Ademe, France (published in proceedings fo ACEEE Summer Study on Energy Efficiency in Buildings)
- Levine MD, JG Koomey, L Price, H Geller, S Nadel (1995). Electricity end-use efficiency: Experience with technologies, markets, and policies througout the world. Energy Vol 20, No 1.
- Linnhoff March. 2000. The Methodology and Benefits of Total Site Pinch Analysis. Linnhoff March Energy Services. Paper can be downloaded from: http://www.linnhoffmarch.com/resources/technical.html
- Martin, N., E. Worrell, M. Ruth, and L. Price, R. N. Elliott, A. M. Shipley, and J. Thorne. 2000. Emerging Energy-Efficient Industrial Technologies. LBNL/ACEEE, Berkeley, CA/Washington, DC.
- Munkejord, M. (2006). Saving the answer. Energy saving is without doubt the quickest, most effective and most cost-effective manner for reducing greenhouse gas emissions. Montel Powernews No1 2006.
- Nadel, S. M Shepard, S Greenberg, G Katz, Annibal T. de Almeida (1992). Energy Efficient Motor Systems. A Handbook on Technology, Program, and Policy Opportunities. American Council for an Energy Efficient Economy, Washington, DC, and Berkeley, California.
- Petersdorff, C., T. Boermans, O. Stobbe, S. Joosen, W. Graus, E. Mikkers and J. Harnisch (2003). Mitigation of CO_2-Emissions from the Building Stock: Beyond the EU Directive on the Energy Performance of Buildings. By Ecofys for Eurima/Euroace. Germany.
- Phylipsen, G.J.M., K. Blok, E. Worrell (1998). Handbook on International Comparison of Energy Efficiency in the Manufacturing Industry. Department of Science, Technology and Society, Utrecht University, The Netherlands.
- Phylipsen, G.J.M., E. Worrell, N.C. Martin and D. Einstein (1999). Energy efficiency improvement in the production of ethylene and other petrochemicals. LBNL, Berkeley, US.
- Phylipsen, G.J.M., W. Graus, K. Blok, Y. Hofman and M. Voogt (2003). International Comparisons Of Energy Efficiency - Results For Iron & Steel, Cement And Electricity Generation. Ecofys, Utrecht, the Netherlands. Commissioned by the National Institute of Public Health and Environment (RIVM).
- Sinton, J.E., J.I. Lewis, L.K. Price and E. Worrell (2002). China's sustainable energy future scenarios and carbon emissions analysis. Subreport 11:

international trends in energy-efficiency technologies and policies. LBNL, Berkeley, US.

- USCAR (2002). Information provided by the United States Council for Automotive Research (USCAR), co-operation between DaimlerChrysler, Ford and General Motors, www.uscar.org, accessed June 2002. USA
- UU (2001). Icarus-4. Universiteit Utrecht. The Netherlands.
- Von Weizsäcker, E., A.B. Lovins and L.H. Lovins (1998). Factor Four, Earthscan. London, UK.
- WBCSD (2005). Pathways to 2050. Energy and climate change. World Business Council for Sustainable Development. Switzerland.
- Weiss, M.A., J.B. Heywood, E.M. Drake, A. Schafer and F.F. AuYeung (2000). On the Road in 2020. Energy Laboratory, MIT, Cambridge, Massachusetts, USA.
- Worrell, E. (1994). Potential for Improved Use of Industrial Energy and Materials. PhD Thesis University of Utrecht, The Netherlands.
- Worrell, E., N.C. Martine and L. Price (1999). Energy Efficiency and Carbon Dioxide Emissions Reduction Opportunities in the U.S. Iron and Steel Sector. LBNL, Berkeley, US.
- Worrell, E. and C. Galitsky (2005). Energy Efficiency Improvement and Cost Saving Opportunities For Petroleum Refineries. Lawrence Berkeley National Laboratory.