ENERGY DEMAND PROJECTIONS FOR ENERGY [R]EVOLUTION 2012

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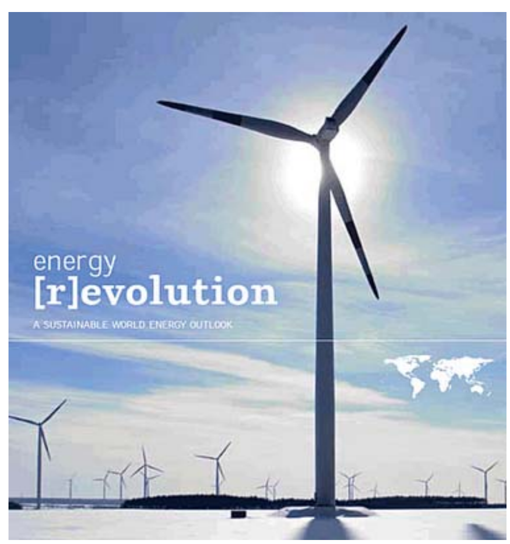

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Executive summary

In this study energy demand scenarios are developed for the 2012 update of the Greenpeace/EREC Energy [R]evolution scenario. These scenarios cover energy demand in the period 2009-2050 for ten world regions (OECD Europe, OECD Americas, OECD Asia Oceania, Eastern Europe/Eurasia, China, India, Other non-OECD Asia, Latin America, Africa and Middle East). Two energy demand scenarios have been defined:

1. a reference projection that follows business as usual trends and
2. a low energy demand scenario, that takes into account the implementation of a certain amount of energy-efficiency measures.

The reference scenario is based on the IEA World Energy Outlook (WEO) 2011 edition up to 2035 and is extrapolated by GDP projections for the period 2035-2050. The scenarios cover energy demand development for three sectors; (1) transport, (2) industry and (3) others (also referred to as “buildings and agriculture”). Per sector a distinction is made between (1) electricity demand and (2) fuel and heat demand (also called fuels).

Figure 1 shows the reference scenario for global energy demand per sector. Following business as usual conditions, worldwide final energy demand is expected to grow by 72%, from 304 EJ in 2009 to 523 EJ in 2050.

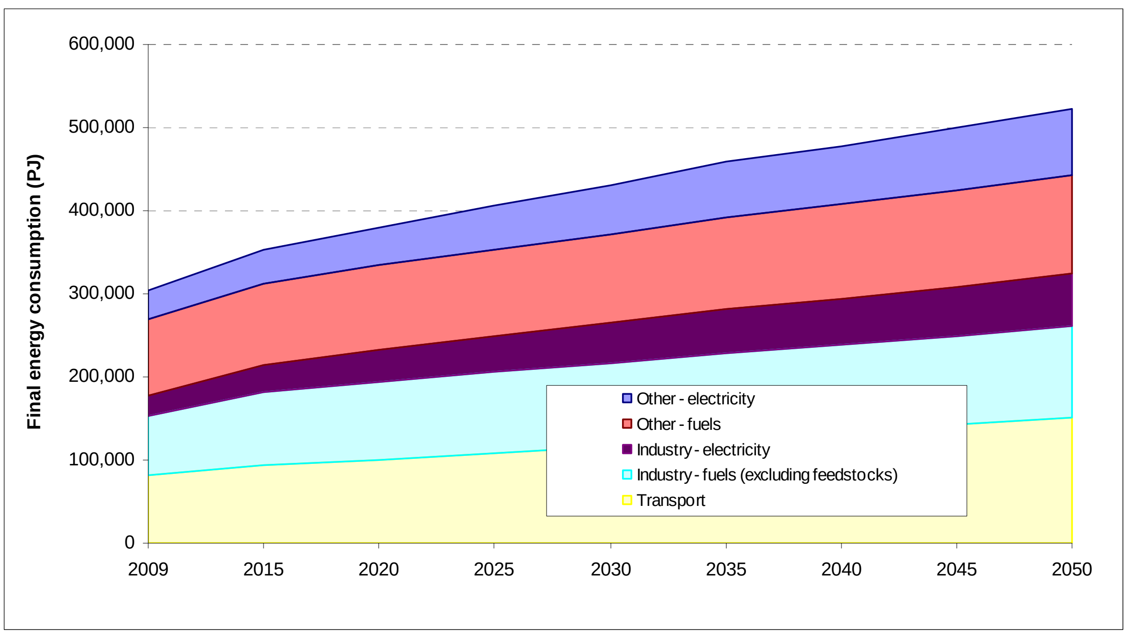

Figure 1 Final energy demand (PJ) in reference scenario per sector worldwide

Figure 2 shows a regional breakdown of the final energy demand. In the reference scenario, final energy demand in 2050 will be largest in China (112 EJ), followed by OECD Americas (81 EJ) and OECD Europe (59 EJ). Final energy demand in OECD Asia Oceania and Latin

America will be lowest (21 EJ and 31 EJ respectively).

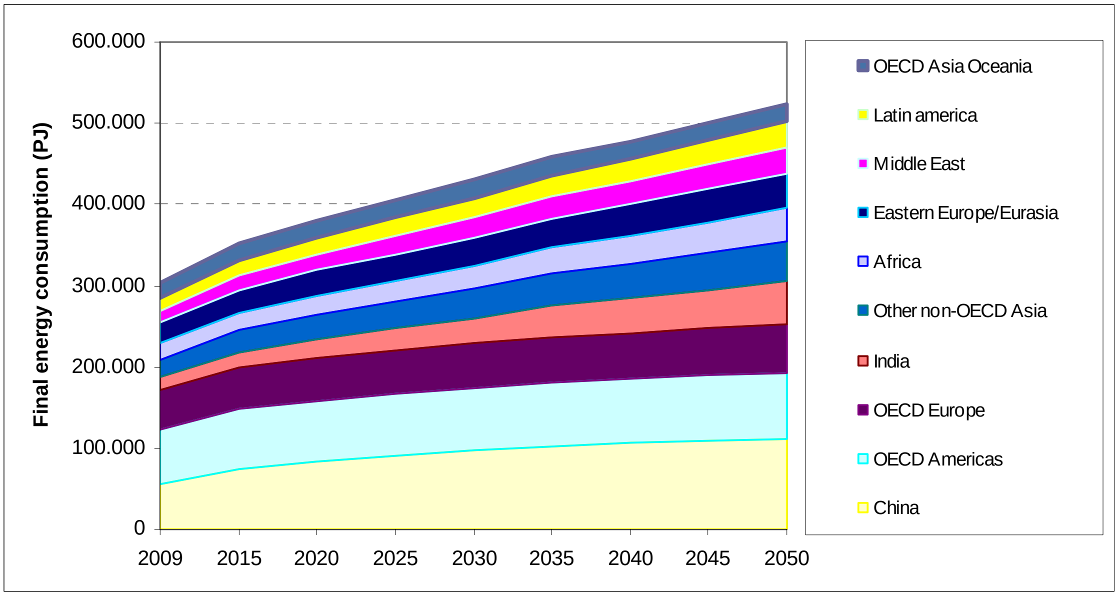

Figure 2 Final energy demand (PJ) in reference scenario per region

For the sectors Others and Industries energy [r]evolution scenarios are developed in this study per region. In these scenarios the final energy demand is reduced by the implementation of energy-efficiency measures. Key energy-efficiency measures are:

- Implementation of best available technologies in industries
- Increased material efficiency and recycling
- Insulation of existing buildings, improved heating and cooling systems and new efficient buildings with a low demand for heating and cooling
- Efficient household and commercial electric appliances

Figure 32 shows the energy [R]evolution scenario for the sector buildings and agriculture. Energy demand savings in comparison to reference levels represent 36% for electricity use and 28% for fuel use, in 2050. In comparison to 2009, global fuel use in buildings and agriculture decreases slightly from 91 EJ to 86 EJ while electricity use shows a strong increase from 35 EJ to 52 EJ.

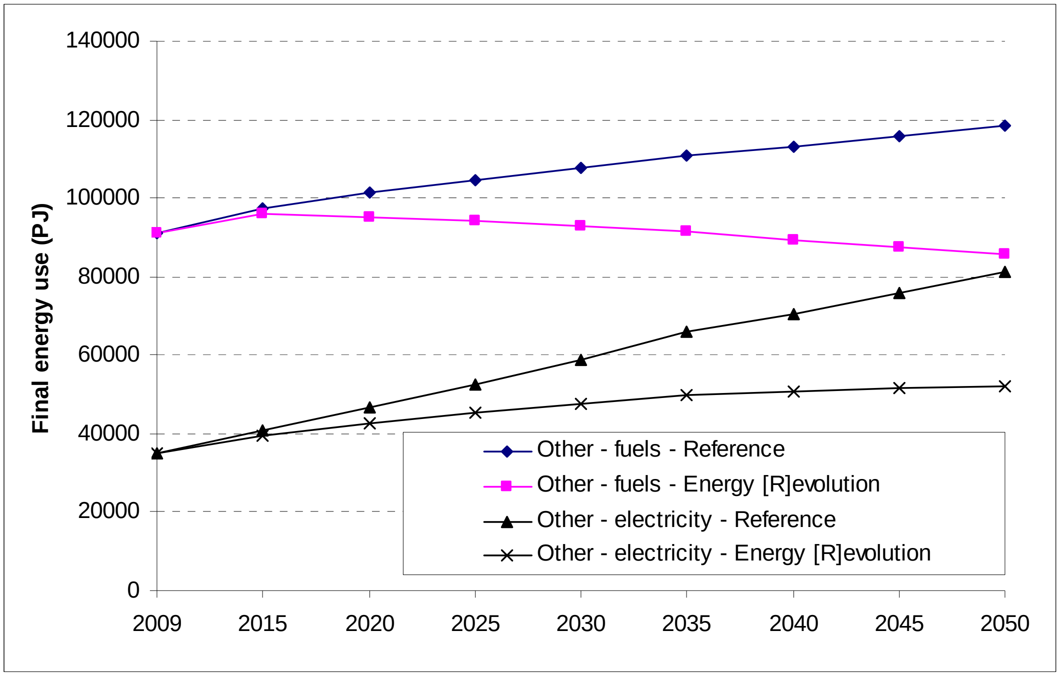

Figure 3 Global final energy use in the period 2009-2050 in Others

Figure 32 shows the energy demand scenarios for industry. Energy demand savings represent 33% for electricity use and 35% for fuel use, in comparison to the reference level in 2050. In comparison to 2009, global fuel use in industry increases slightly from 71 EJ to 72 EJ and electricity use shows a stronger increase from 24 EJ to 43 EJ.

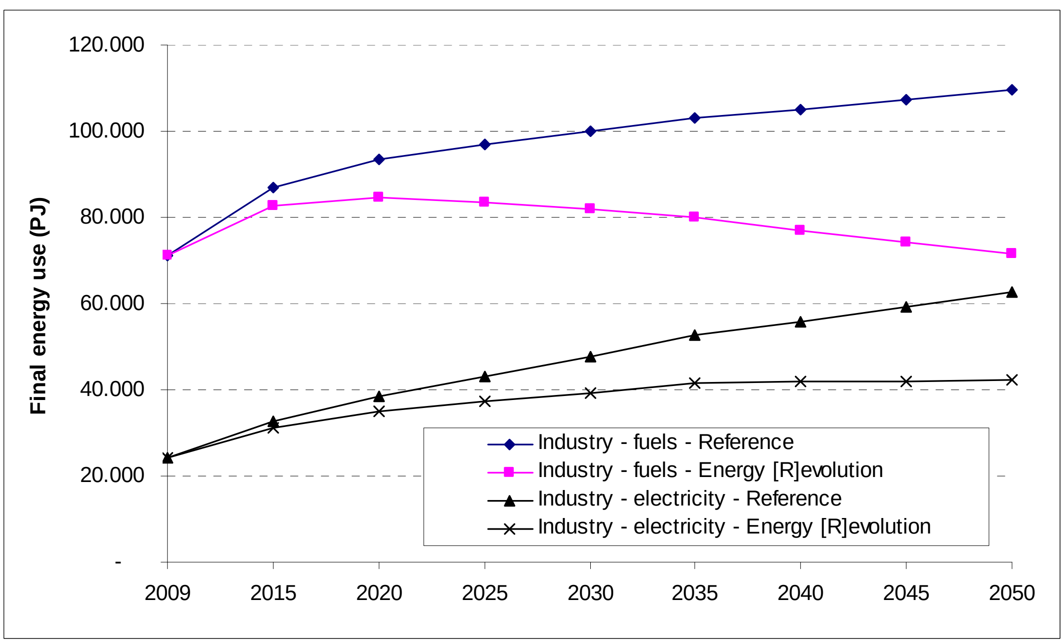

Figure 4 Global final energy use in the period 2009-2050 in industry

Incremental investment costs needed for implementing the energy-efficiency measures in the energy [R]evolution scenario are estimated to be around 1% of GDP, annually. These costs are in addition to investment costs already occurring under the reference scenario. They do not include benefits from energy-efficiency measures in terms of energy savings.

List of abbreviations and definitions

Abbreviations

GDP	Gross domestic product
g.e.	Gasoline equivalent (1 litre g.e. is equal to 34.8 MJ)
IEA	International Energy Agency
LDV	Light duty vehicles
PPP	Purchasing power parities
p.km	Passenger kilometre
t.km	Tonne kilometre
v.km	Vehicle kilometre
WEO	World Energy Outlook
yr	Year
HDD	Heating Degree Day

Definitions

Energy intensity	Final energy use per unit of gross domestic product
Energy efficiency	Final energy use per unit of physical indicator (tonne steel, kWh, m^2 building surface etc)
Reference scenario	Final energy demand when current trends continue
Low energy demand scenario	Final energy demand when energy-efficiency measures are implemented

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1 Introduction

The goal of this study is to develop energy demand scenarios for the 2012 Energy [R]evolution scenario. In the previous analysis "Global low energy demand scenarios (Ecofys, 2008)" we made two low energy demand scenarios which were used in the Greenpeace/EREC Energy [R]evolution scenario in 2008 and 2010. This study foresees in an update of the scenarios. The energy demand scenarios cover energy demand in the period 2009-2050 for ten world regions and three sectors: (1) transport, (2) industry and (3) buildings and agriculture (also referred to as "others").

This report explains in Chapter 2 the methodology used for developing the reference and low energy demand scenarios. Chapter 3 gives detailed assumptions for the low energy demand scenarios and describes energy-efficiency measures for the sectors industry and others, respectively. Chapter 4 presents the results per region. Finally, needed policy measures and investments to achieve the low energy demand scenarios are discussed in Chapter 5.

2 Methodology

This section explains the methodology for developing the energy demand projections. The approach includes two steps:

1. Definition of reference energy demand
2. Development of low energy demand scenarios including potentials for energy-efficiency improvement

2.1 Step 1: definition of reference scenario

Step 1 concerns the definition of a reference scenario. In order to estimate potentials for energy-efficiency improvement in 2050 it is needed to develop a detailed reference scenario that projects the development of energy demand when current trends continue. In the reference scenario, only currently adopted energy and climate change policies are implemented. Technological change, thus efficiency improvement, is slow but substantial, and mainly triggered by increased energy prices (IEA, 2011a).

The reference scenario is based on the World Energy Outlook (WEO) of the International Energy Agency (IEA, 2011a). The IEA WEO 2011 edition (shortly WEO 2011) provides the most detailed energy scenario on a global level. The WEO 2011 Current Policies Scenario that is used in the construction of the reference scenario runs from 2009-2035. For the period 2035-2050 the WEO scenario is extended by assumptions regarding GDP and energy intensity developments.

The reference scenario covers energy demand development in the period 2009-2050 for ten world regions and three sectors. These sectors are (1) transport, (2) industry and (3) others (also referred to as “buildings and agriculture”). Per sector a distinction is made between (1) electricity demand and (2) fuel and heat demand. Heat demand mainly consists of district heating from heat plants and from combined heat and power plants. Fuel and heat demand is shortly referred to as fuel demand. The energy demand scenario focuses only on energy-related fuel, power and heat use. This means that feedstock consumption in industries is excluded from the analysis. Total final consumption data in WEO include non-energy use. By assuming that the share of non-energy use remains the same as in the base year 2009 we determine the energy-related fuel use beyond 2009.

In this section we will give a brief overview of assumptions used to build the reference scenario and the resulting energy use levels:

- Definition world regions
- Population development
- GDP development
- Energy-intensity development
- Reference scenario

Definition world regions

This study focuses on 10 world regions. The regional disaggregation in this study is the same as the one used in the WEO 2011 edition (IEA, 2011a). The regional definitions are given in the table below.

Table 1: Specification of world regions (IEA, 2011a)

World region	**Countries**
OECD Europe	Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom. For statistical reasons, this region also includes Israel.
OECD Americas	Canada, Mexico, Chile and United States.
OECD Asia Oceania	Japan, South Korea, Australia and New Zealand.
Eastern Europe/Eurasia	Albania, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Georgia, Kazakhstan, Kyrgyz Republic, Latvia, Lithuania, Former Yugoslav Republic of Macedonia, Republic of Moldova, Romania, Russian Federation, Serbia, Tajikistan, Turkmenistan, Ukraine and Uzbekistan. For statistical reasons, this region also includes Cyprus, Gibraltar and Malta.
China	People's republic of China and Hong Kong,
India	India
Other non-OECD Asia	Bangladesh, Brunei Darussalam, Cambodia, Chinese Taipei, Indonesia, Democratic People's Republic of Korea, Malaysia, Mongolia, Myanmar, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Thailand, Vietnam and other non-OECD Asian countries (Afghanistan, Bhutan, Cook Islands, East Timor, Fiji, French Polynesia, Kiribati, Laos, Macau, Maldives, New Caledonia, Papua New Guinea, Samoa, Solomon Islands, Tonga and Vanuatu).
Latin America	Argentina, Bolivia, Brazil, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, Trinidad and Tobago, Uruguay, Venezuela and other Latin American countries (Antigua and Barbuda, Aruba, Bahamas, Barbados, Belize, Bermuda, British Virgin Islands, Cayman Islands,. Dominica, Falkland Islands, French Guyana, Grenada, Guadeloupe, Guyana, Martinique, Montserrat, St. Kitts and Nevis, Saint Lucia, Saint Pierre et Miquelon, St. Vincent and the Grenadines, Suriname and Turks and Caicos Islands).
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, Malawi, 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, Islamic Republic of Iran, Iraq, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, United Arab Emirates and Yemen. It includes the neutral zone between Saudi Arabia and Iraq.

Population development

The WEO 2011 is based on the most recent United Nation projections for population development (UN, 2011) up to 2035. For the reference scenario, the same population projections are applied, for the expanded time frame until 2050. Figure 5 shows the population per region in the reference scenario.

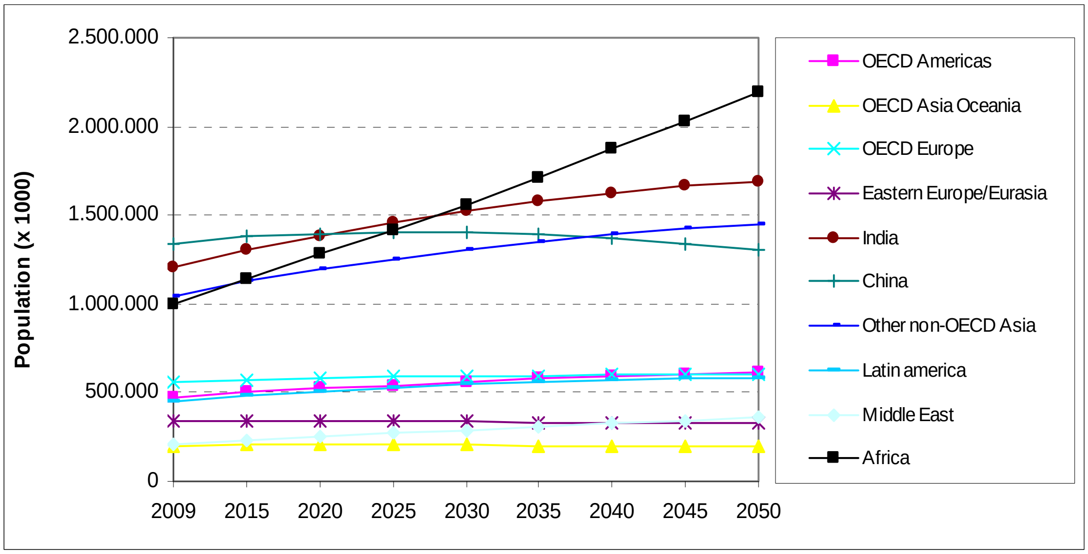

Figure 5 Population projection in reference scenario

According to the projection, Africa will have the highest number of inhabitants in 2050, around 2.2 billion, followed by India, Other non-OECD Asia and China are estimated to have around 1.5 billion inhabitants. OECD Americas, OECD Europe and Latin America are around 0.6 billion and Middle East, Eastern Europe/Eurasia and OECD Asia Oceania between 0.2 - 0.4 billion inhabitants, each.

GDP growth rate

The WEO projects energy demand on a regional level for the period 2009 to 2035. This scenario is extended for the period 2035-2050 based on:

- The growth rate of gross domestic product (GDP), corrected for purchase power parity for the period 2035-2050 (% per year), assessed by DLR (personal communication, 2012).
- An assumed energy intensity[1] decrease based on the trend in the WEO for the period 2009-2035 (% per year).

GDP development is discussed in this section and the energy intensity decrease is discussed in the next section.

All data on economic development in the WEO 2011 refer to purchasing power adjusted GDP. We follow this approach, and all GDP data in this report are expressed in real US dollars using purchasing power parities (PPP). Purchasing power parities (PPP) compare costs in different currencies of a fixed basket of traded and non-traded goods and services and yield a widely-based measure of standard living. Therefore they have a more direct link with energy use than GDP based on market exchange rates.

Since the WEO only covers the time period up to 2035, assumptions are made regarding the economic growth between 2035 and 2050. DLR assessed GDP growth rates for the period 2035-2050 (DLR, personal communication, 2012), where the GDP growth in all regions is expected to slow gradually over the next decades, following the trends in the period 2009-2035.

The economic growth assumptions are summarised in Table 2.

Table 2: GDP development projections (average annual growth rates) (2009-2035: IEA (2011a) and 2035-2050: DLR, personal communication (2012))

	2009-2020	2020-2035	2035-2050	2009-2050
World	4.2%	3.2%	2.2%	3.1%
OECD Americas	2.7%	2.3%	1.2%	2.0%
OECD Asia Oceania	2.4%	1.4%	0.5%	1.3%
OECD Europe	2.1%	1.8%	1.0%	1.6%
Eastern Europe/Eurasia	4.2%	3.2%	1.9%	3.0%
India	7.6%	5.8%	3.1%	5.3%
China	8.2%	4.2%	2.7%	4.7%
Other non-OECD Asia	5.2%	3.2%	2.6%	3.5%
Latin America	4.0%	2.8%	2.2%	2.9%
Middle East	4.3%	3.7%	2.8%	3.5%
Africa	4.5%	4.4%	4.2%	4.4%

Figure 6 shows the resulting developments for GDP per capita.

[1] Energy intensity is here defined as final energy use per unit of gross domestic product.

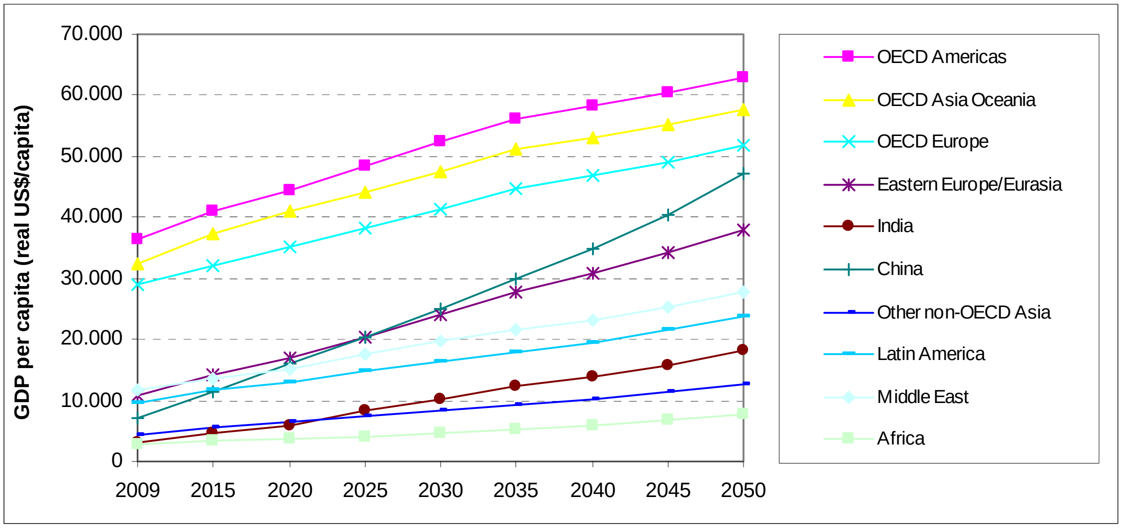

Figure 6 GDP / capita development (real US$/capita)

The figure shows that GDP per capita is expected to be highest in 2050 in OECD Americas and OECD Asia Oceania ~~Pacific~~ (63,000 and 58,000 US$ per capita respectively), followed by OECD Europe (52,000 US$ per capita) and China (47,000 US$ per capita). Africa and Other non-OECD Asia are expected to have the lowest GDP per capita (8,000 and 13,000 US$ per capita, respectively).

Energy-intensity decrease in reference scenario

The energy intensity of an economy is in this study defined as final energy use per unit of gross domestic product. The energy intensity in an economy tends to decrease over time. This can be a result of a number of factors such as:

- Autonomous energy efficiency improvement, which occurs due to technological developments. Each new generation of capital goods is likely to be more energy efficient than the one before.
- Policy-induced energy efficiency improvement as a result of which economic actors change their behaviour and invest in more energy efficient technologies or improve energy management.
- Structural changes that can have a downward or upward effect on the economy's energy intensity. An example of a downward effect is a shift in the economy away from energy-intensive industrial activities to services related activities. Also there can be demand saturation in certain sectors or countries. For instance in a country with already comparatively high volumes of passenger travel, the increase of GDP may lead to a lower than linear increase of passenger travel and thereby decreasing energy-intensity.

Only the first two are regarded in this study as energy-efficiency improvement. Energy efficiency improvement is defined as the decrease in specific energy consumption per physical unit of energy service (e.g. GJ/tonne crude steel, MJ/passenger km, MJ/m^2 floor surface etc.).

For the calculation of the energy-efficiency potentials it is important to know the energy intensity decrease in the reference scenario that is a result of energy efficiency improvement and the energy intensity decrease that results from structural changes. The total energy intensity decrease in the reference scenario results from a mix of these factors and differs per region and per sector. For the period 2009-2035 the energy-intensity decrease comes directly from the WEO 2011. For the period 2035-2050 the decrease in energy intensity in the different regions and sectors is estimated while taking into account the decreasing trends in the period 2009-2035 reported in WEO. The resulting energy intensity in the reference scenario is shown in Figure 7.

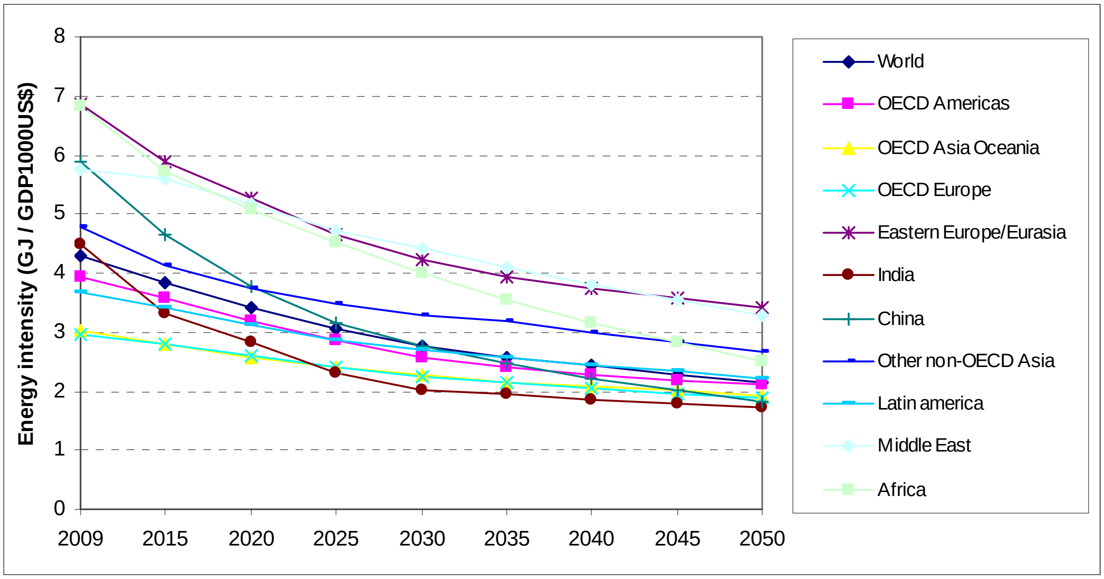

Figure 7 Energy intensity in reference scenario (final energy demand per unit of GDP)

Figure 7 shows that there is a converging trend for energy intensities mainly due to a strong decrease in developing regions. Energy intensities range from 3-7 GJ/$1000GDP in 2009 and from 1.7-3.4 GJ/$1000GDP in 2050. The energy intensity decrease in the reference scenario differs per region, ranging from 1.1 to 2.6%/year as average, for the period 2009-2050. The decrease is different per sector and is typically higher for fuels and lower for electricity use. The share of energy intensity decrease due to energy-efficiency improvement (autonomous or policy induced) is not available for this study. We therefore assume that energy efficiency improvement is equal to 1% per year, based on historical developments of energy efficiency improvement in buildings and industries (see e.g. Ecofys (2005), Blok (2005), Odyssee (2005), IEA (2011c)). When calculating the potential for energy efficiency improvement, the energy efficiency that already occurs is the reference scenario is subtracted from the total potential in order to calculate the remaining potential relative to the reference scenario.

Figure 8 shows yearly GDP growth rates, yearly energy intensity decrease and the resulting yearly growth in final energy demand per region for the reference scenario.

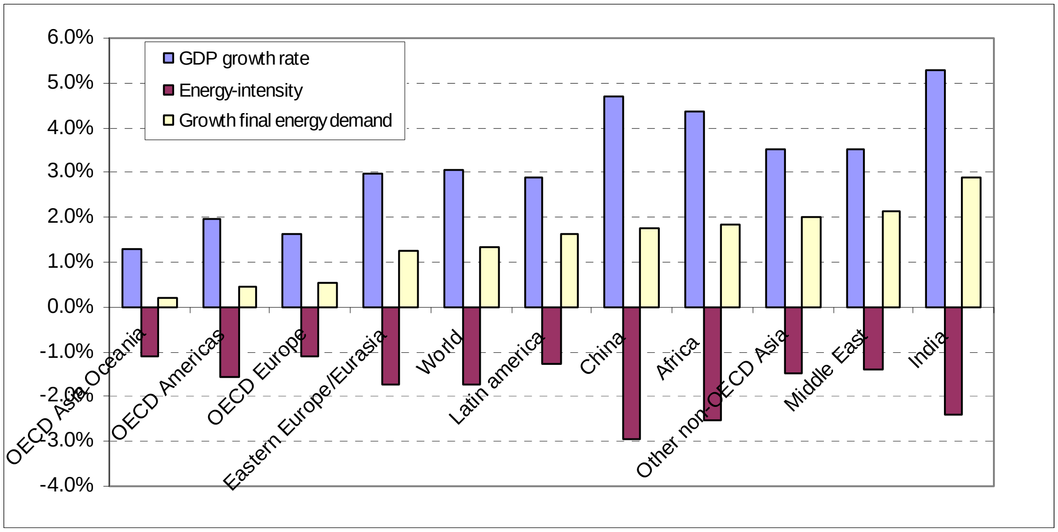

Figure 8 Growth rates of final energy demand, GDP and energy intensity, in % per year in period 2009-2050

The figure shows that final energy demand is projected to increase most in India and Middle East (2.9%/yr and 2.1%/yr), followed by Other non-OECD Asia (2.0%/yr) and Africa (1.8%/yr). Energy demand increase is lowest in OECD Asia Oceania, OECD Americas and OECD Europe (between 0.2%/yr and 0.5%/yr), due to lower GDP growth rates, in combination with moderate energy intensity decrease.

Reference scenario

Figure 9 shows the reference scenario for final energy demand for the world per sector.

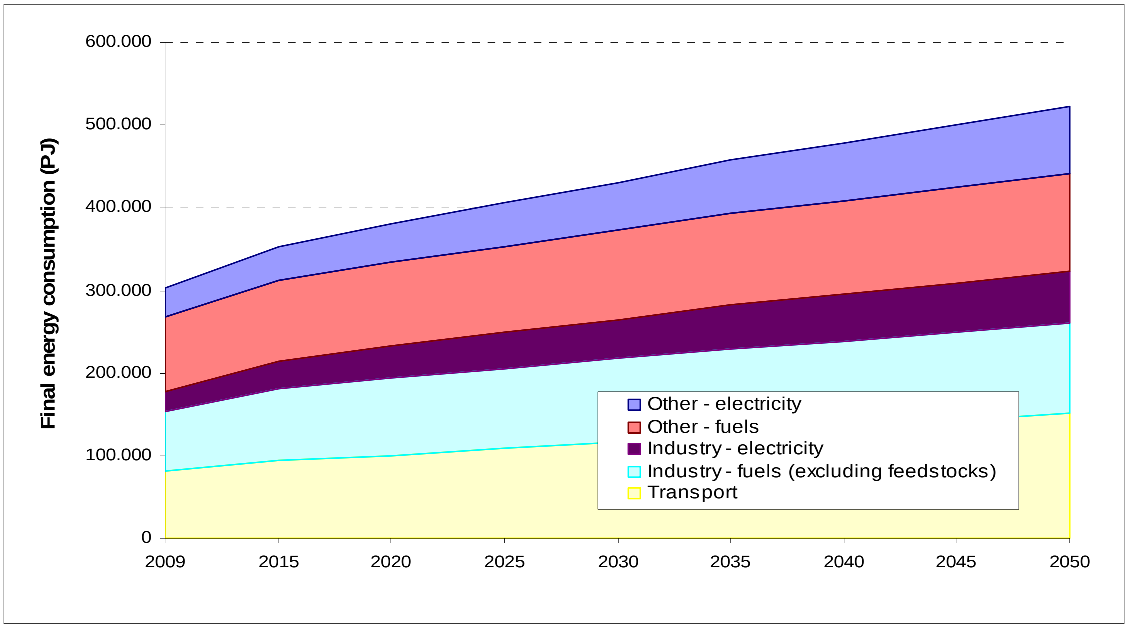

Figure 9 Final energy demand (PJ) in reference scenario per sector worldwide

Worldwide final energy demand is expected to grow by 75%, from 304 EJ in 2009 to 523 EJ in 2050. The relative growth in the transport sector is the largest, where energy demand is expected to grow from 82 EJ in 2009 to 151 EJ in 2050. Fuel demand in Others is expected to grow slowest from 91 EJ in 2009 to 119 EJ in 2050.

Figure 10 shows the final energy demand per region in the reference scenario.

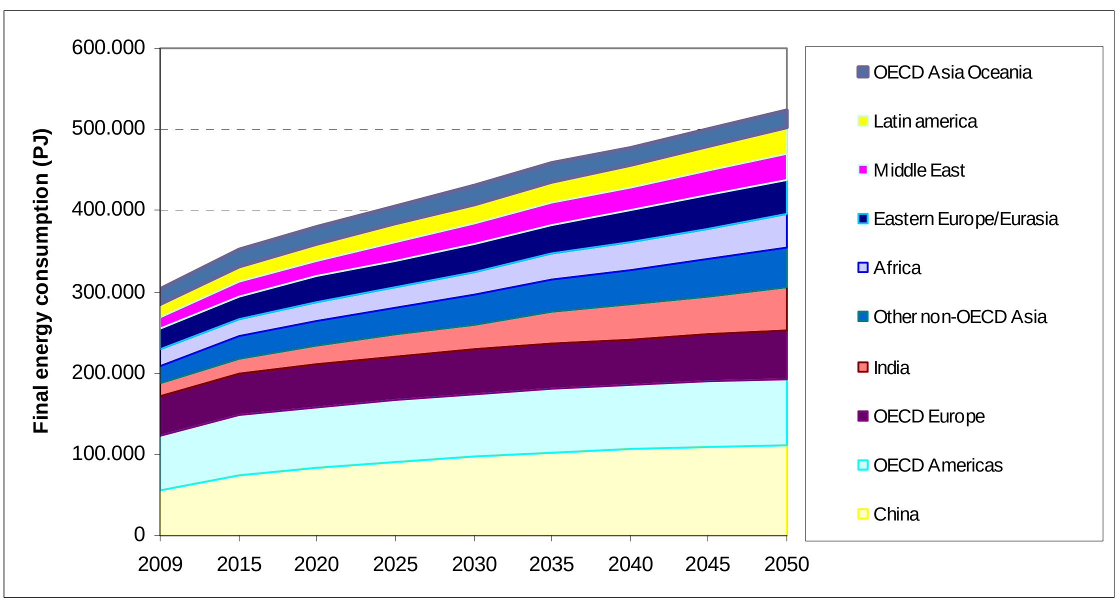

Figure 10 Final energy demand (PJ) in reference scenario per region

In the reference scenario, final energy demand in 2050 will be largest in China (112 EJ), followed by OECD Americas (81 EJ) and OECD Europe (59 EJ). Final energy demand in OECD Asia Oceania and Latin America will be lowest (21 EJ and 31 EJ respectively).

Figure 11 shows the development of final energy demand per capita per region.

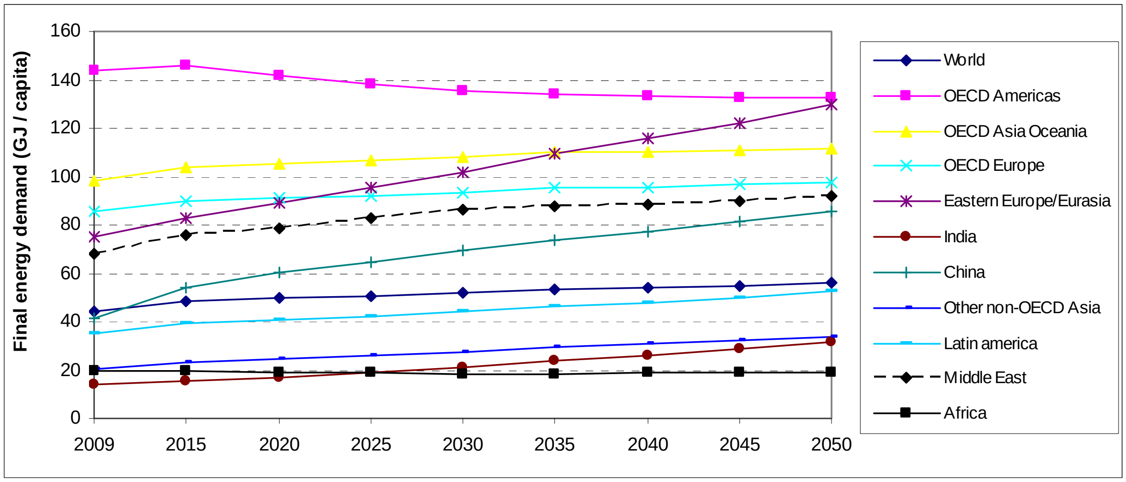

Figure 11 Final energy demand per capita in reference scenario

In terms of final energy demand per capita, there are still large differences between regions in 2050. Energy demand per capita is expected to be highest in OECD Americas and Eastern Europe/Eurasia (130 GJ/capita), followed by OECD Asia Oceania and OECD Europe (111 and 98 GJ/capita respectively). Final energy demand in Africa, India, other non-OECD Asia, and Latin America is expected to be lowest, ranging from 19-56 GJ/capita.

2.2 Step 2: development of low energy demand scenarios

The low energy demand scenarios are based on literature studies and own calculations. The scenarios take into account:

- The implementation of best practice technologies and a certain share of emerging technologies
- No behavioural changes or loss in comfort levels.
- No structural changes in the economy, other than occurring in ~~baseline~~ the reference scenario.
- Equipment and installations are replaced at the end of the (economic) lifetime, so no early retirement.

The selection of measures is based on the current worldwide energy use per sector and sub sector. Figure 12 shows a breakdown of final energy demand in the world by the most important sub-sectors in the base year 2009.

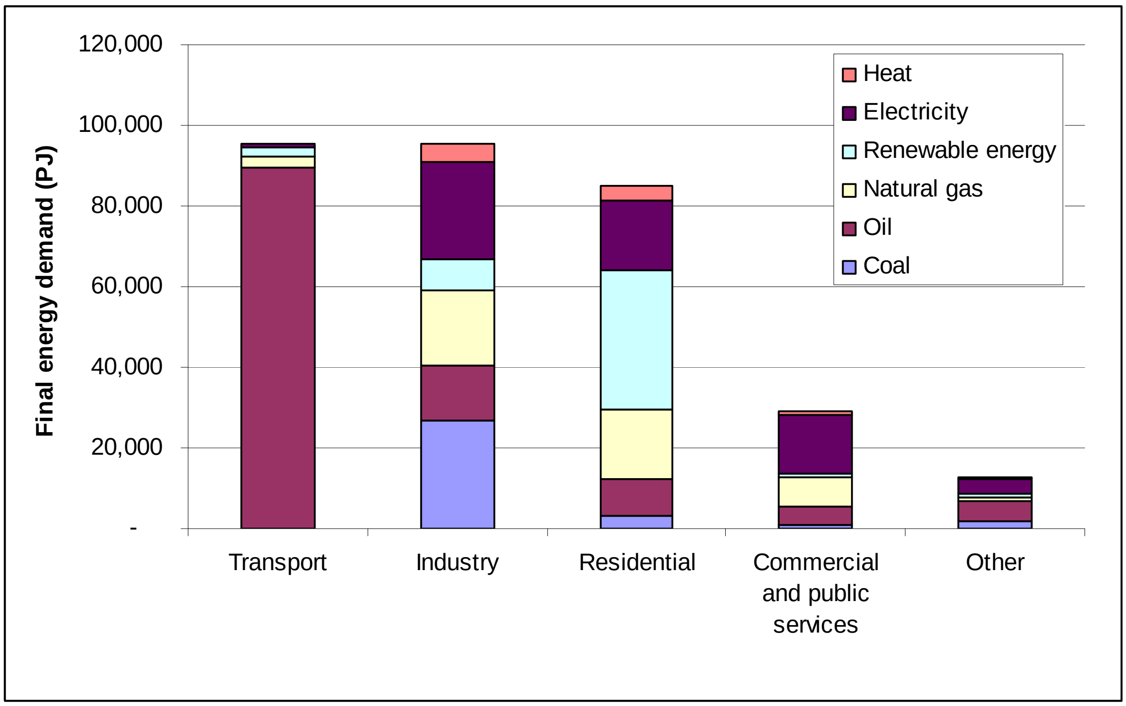

Figure 12 Final energy demand for the world by sub sector and fuel source in 2009 (IEA, 2011b)

Buildings, industry and transport are the three main energy consuming sectors. In Chapter 3 we show in detail the energy use per sector and the selection of the measures per sector. The measures selected, are those expected to result in a substantial reduction of energy demand before 2050.

3 Low energy demand scenarios per sector

This section gives an overview of the measures for energy-efficiency improvement included in the low energy demand scenarios. It is organised by sector: buildings and agriculture (3.1) and industry (3.2).

3.1 Buildings and agriculture

Energy consumed in buildings and agriculture (summarized as "Other Sectors") represents 40% of global energy consumption in 2009 (see Figure 12). In most regions the share of residential energy demand is larger than the share of commercial and public services energy demand (except in OECD Asia Oceania). Since energy use in agriculture is relatively small (globally only 6% of Others) we do not look at this sector in detail but assume the same energy saving potentials as in residential and commercial combined.

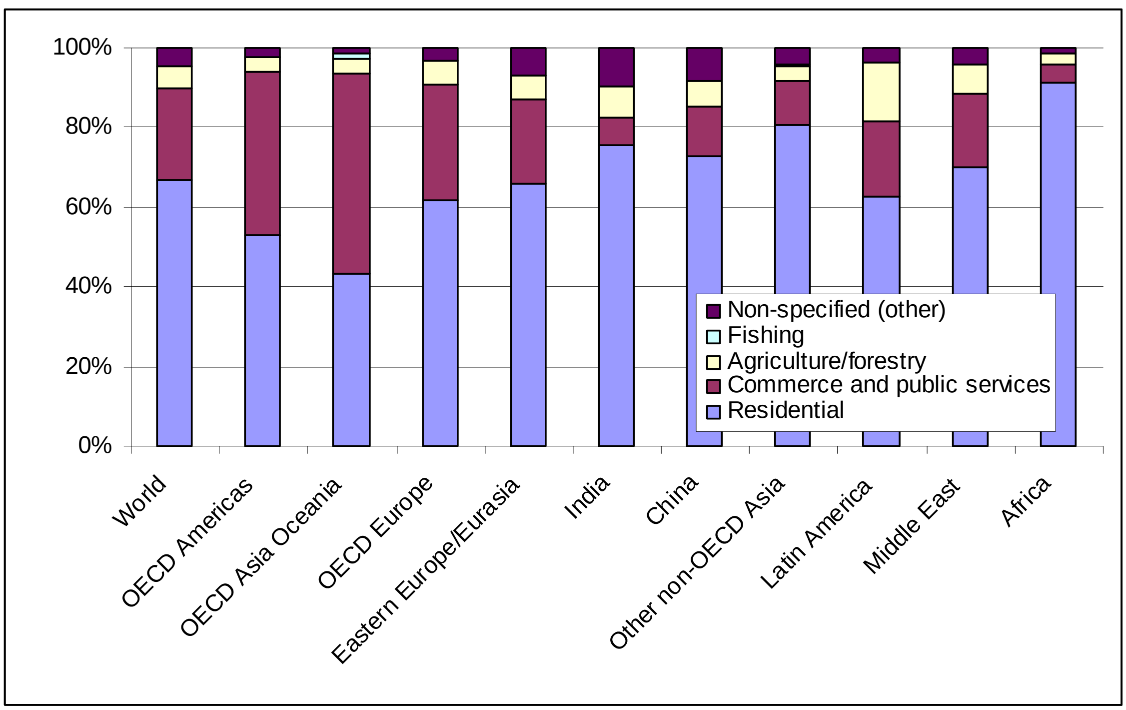

Figure 13 Breakdown of energy demand in buildings and agriculture in 2009 (IEA, 2011b)

In the reference scenario, energy demand in buildings and agriculture is forecasted to grow considerably (see Figure 14).

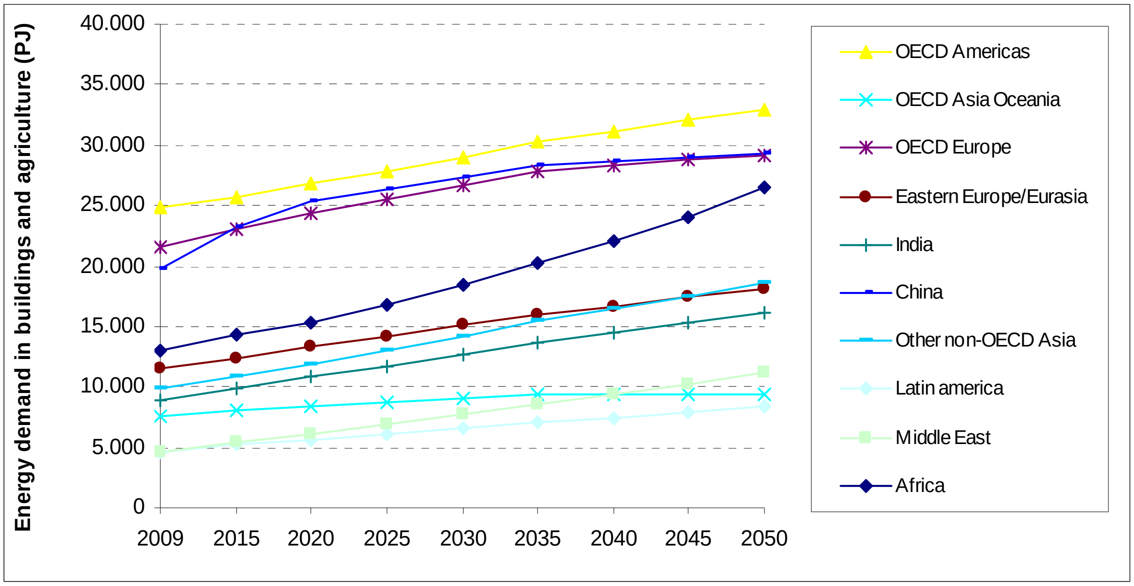

Figure 14 Energy demand in buildings and agriculture in reference scenario per region

Figure 14 shows that energy demand in buildings and agriculture in 2050 is highest in OECD Americas, followed by China and OECD Europe. Latin America, OECD Asia Oceania and Middle East have the lowest energy demand for buildings and agriculture.

The share of fuel and electricity use by buildings and agriculture in total energy demand in 2009 and 2050 are shown in Figure 15. India and Africa have the highest share of buildings and agriculture in total final energy demand. Until 2050, for India a sharp decrease is expected. Globally it is expected that electricity use in the sector Others will be relatively more important in 2050 than in 2009 (16% instead of 12%) and fuel use will be relatively less important (23% instead of 30%).

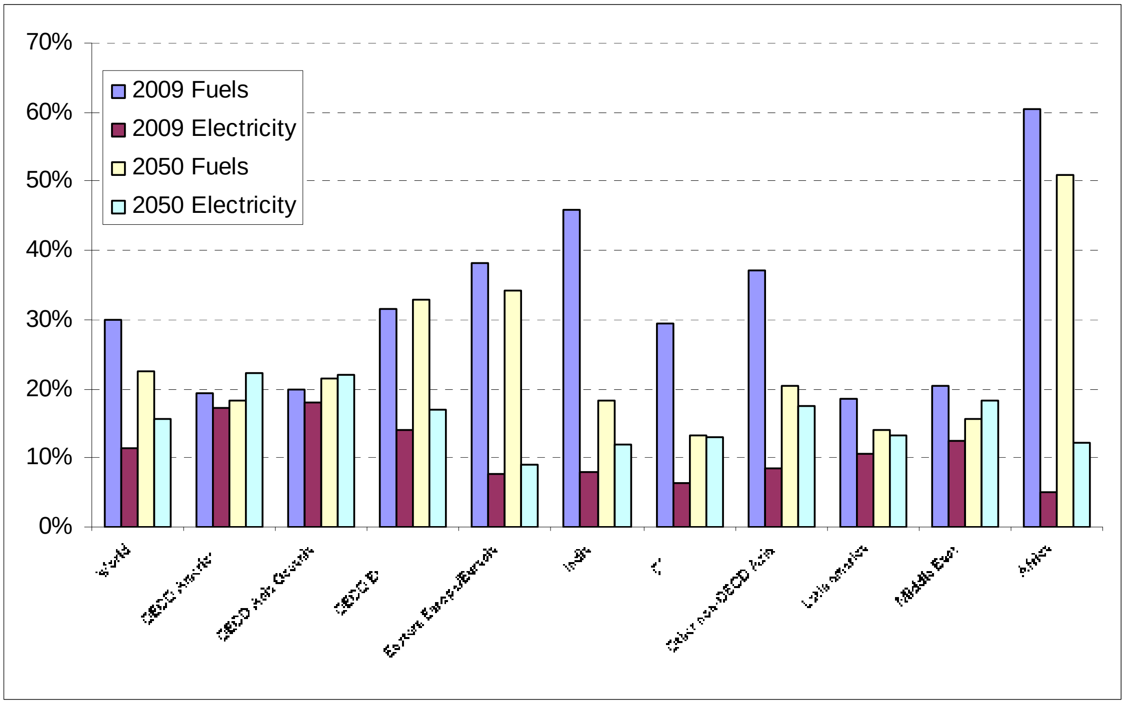

Figure 15 Share electricity and fuel consumption by Others in total final energy demand in 2009 and 2050 in the reference scenario

Figure 16 and Figure 17 give the development of energy use per capita and GDP per region. As can be seen there are still large differences expected in terms of energy use per capita in 2050.

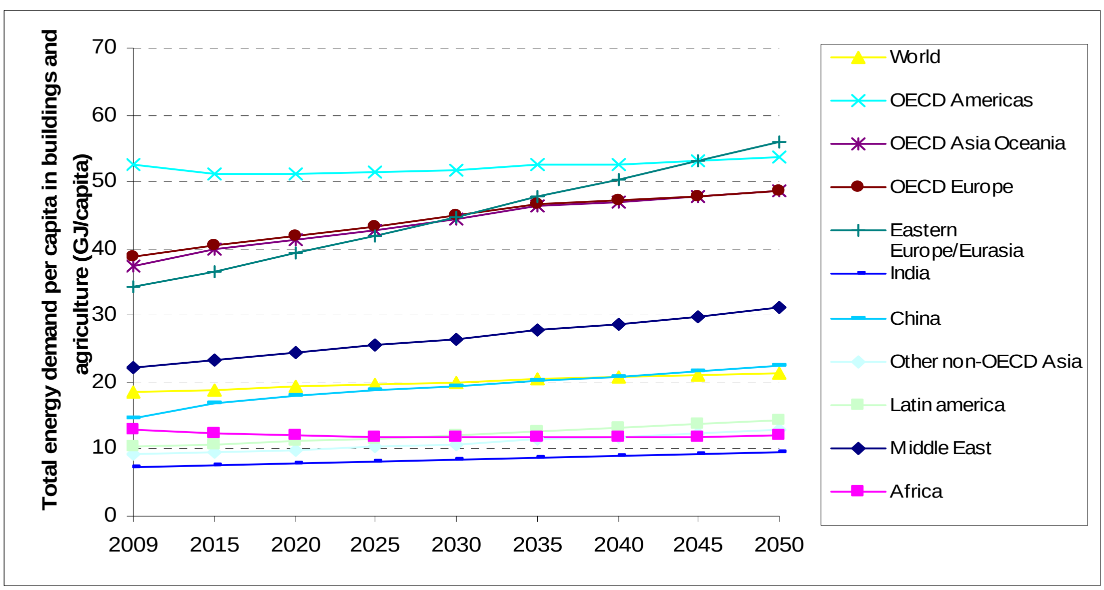

Figure 16 Final energy demand per capita per region in Others in the reference scenario

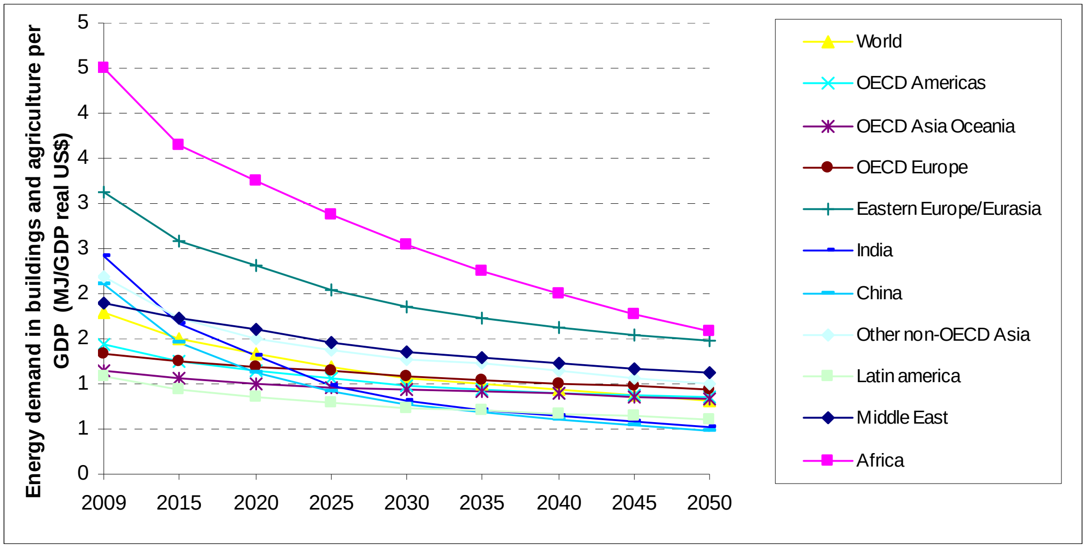

Figure 17 Final energy demand per unit of GDP_{ppp} per region in Others in the reference scenario

In the next sections we look at measures for reducing fuel and heat use (3.1.1), measures for reducing electricity use (3.1.2) and assumptions used for the low energy demand scenarios (3.1.3).

3.1.1 Fuel and heat use

Fuels and heat use represent the largest share of total final energy use in the Others, see Figure 18. The share ranges from 52% for OECD Asia Oceania to 92% for Africa.

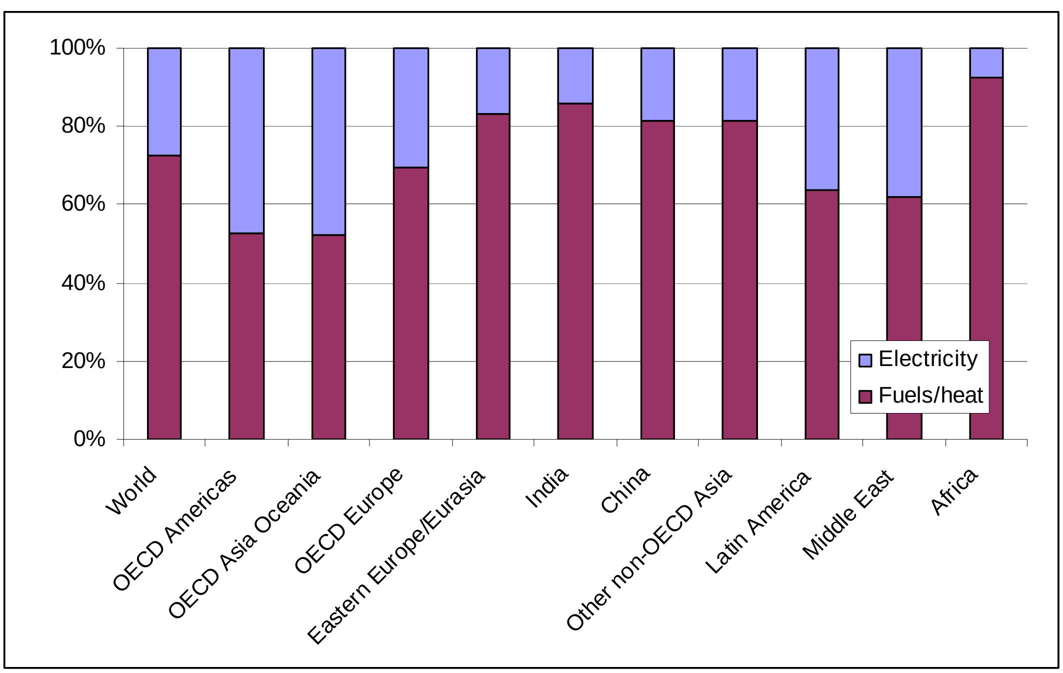

Figure 18 Breakdown of final energy demand in 2009 for electricity and fuels/heat in Others (IEA, 2011b)

The largest end use sector for fuels and heat use is the residential sector, see Figure 19. The share ranges from 45% in OECD Asia Oceania to 94% in Africa.

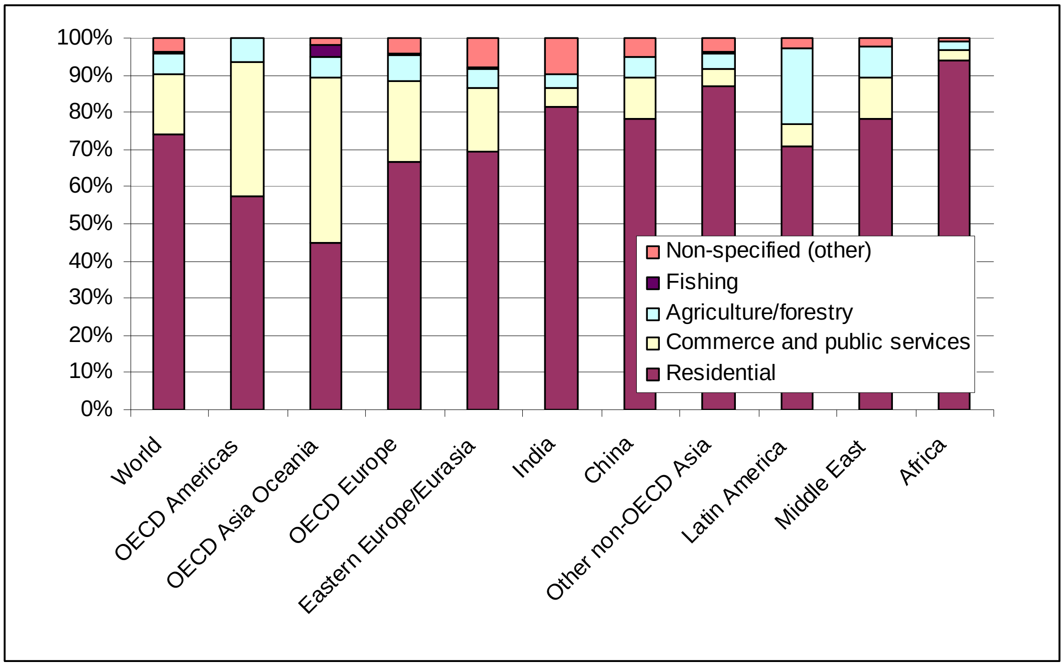

Figure 19 Breakdown of fuel and heat use in Other in 2009 (IEA, 2011b)

Currently the largest share of fuel and heat use in the sector Others is used for space heating. The breakdown of fuel use per function is different per region. In the [r]evolution scenario a convergence is assumed for the different types of fuel demand per region. Based on Bertoldi & Atanasiu (2006), IEA (2006), IEA (2007) and WBCSD (2005), the following breakdown for fuel use in 2050 is assumed for all regions:

- space heating (80%)
- hot water (15%)
- cooking (5%)

We now give a summary of possible energy saving measures for the three types of fuel/heat use.

Space heating

An indicator for energy-efficiency improvement for space heating is the energy demand per m^2 floor area per heating degree day (HDD). Heating degree day is the number of degrees that a day's average temperature is below 18^o Celsius, the temperature below which buildings need to be heated. Typical current heating demand for dwellings in OECD countries is 70-120 kJ/m^2/HDD (based on IEA, 2007). Dwellings with a low energy use consume below 32 kJ/m^2/HDD[2]. An example of a household with low energy use is given in Figure 20 below.

[2] This is based on a number of zero-energy dwelling in the Netherlands and Germany, consuming 400-500 m^3 natural gas per year, with a floor surface between 120 and 150 m^2. This results in 0.1 GJ/m^2/yr and is converted by 3100 heating degree days to 32 kJ/m^2/HDD.

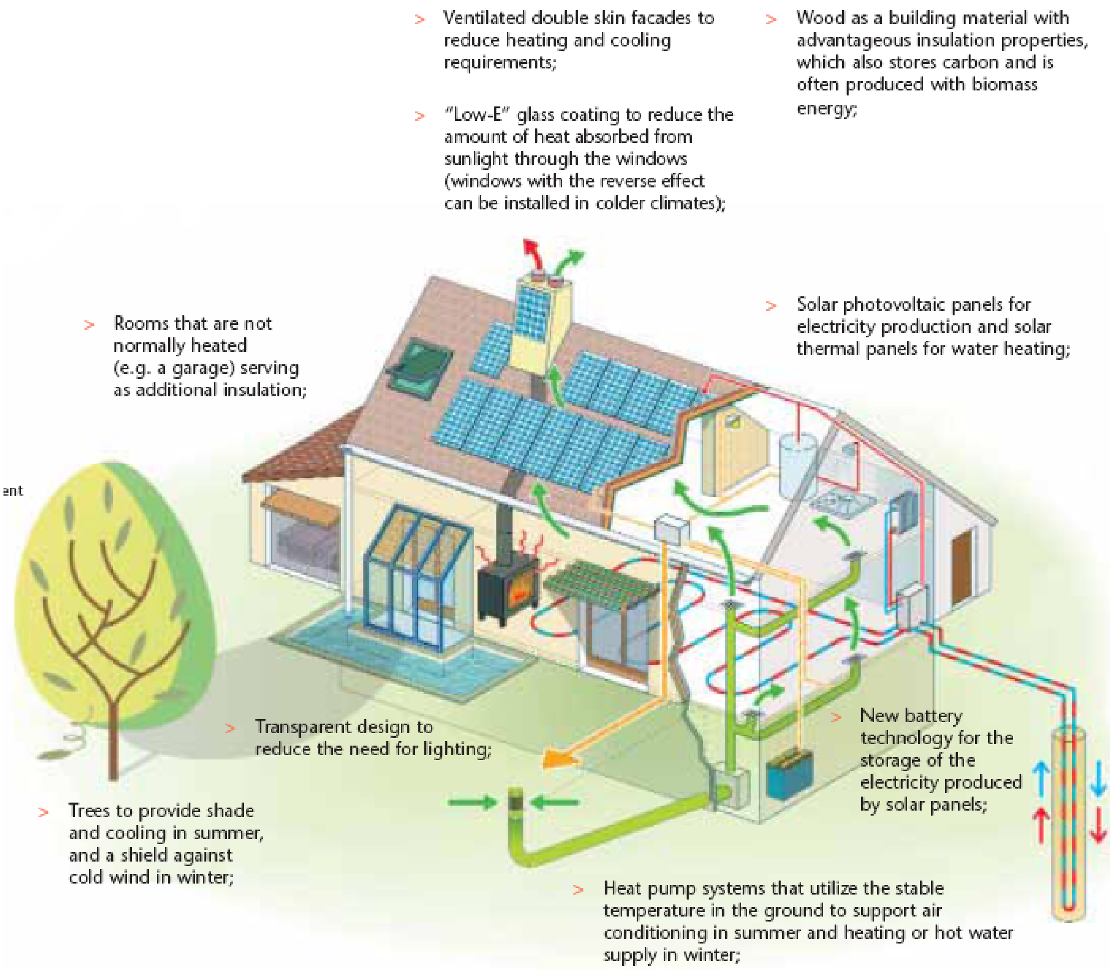

Figure 20 Elements of new building design that can substantially reduce energy use (WBCSD, 2005)

Technologies to reduce energy demand of new dwellings are (WBCSD (2005), IEA (2006), Joosen et al (2002):

- Triple-glazed windows with low-emittance coatings. These windows reduce heat loss to 40% compared to windows with one layer. The low-emittance coating prevents energy waves in sunlight coming in and thereby reduces cooling need.
- Insulation of roofs, walls, floors and basement. Proper insulation reduces heating and cooling demand by 50% in comparison to average energy demand.
- Passive solar energy. Passive solar techniques make use of the supply of solar energy by means of building design (building's site and window orientation). The term "passive" indicates that no mechanical equipment is used. All solar gains are brought in through windows.
- Balanced ventilation with heat recovery. Heated indoor air passes to a heat recovery unit and is used to heat incoming outdoor air.

For existing buildings there is a potential for retrofitting of buildings. Important retrofit options are more efficient windows and insulation. According to IEA (2006), the former can save 39% of space heating energy demand of existing buildings, while the latter can save 32% of space heating or cooling energy demand. IEA (2006) reports that average energy consumption in current buildings in Europe can decrease by more than 50%.

To improve the efficiency of existing heating systems, an option is to install new thermostatic valves (TRV). This option can save 15% of energy compared to the situation without TRV. EU-average implementation of this option is estimated at 40% (Bettgenhäuser et al. 2009).

Besides reducing the demand for heating, another option is to improve the conversion of efficiency of heat supply. To this effect a number of options are available such as high efficiency boilers that can achieve efficiencies of 107%, based on lower heating value. Another option is the use of heat pumps (see section 3.1.2).

Hot water and cooking

Energy savings options for hot water include pipe insulation and high efficiency boilers. Another option is heat recovery units that use waste heat from exhaust water. Hot water that goes down the drain carries energy with it. Heat recovery systems capture this energy to preheat cold water entering the water heater. A heat recovery system can recover as much as 70% of this heat and recycle it back for immediate use (Enviroharvest, 2008). Furthermore water saving shower heads and flow inhibitors can be implemented. The typical saving rate (in terms of energy) for shower heads is 12,5% and 25% for flow inhibitors (Bettgenhäuser et al. 2009). In developing regions, improved coke stoves can be an important energy-efficiency option, which consume less energy than conventional ones (REEEP, 2009).

3.1.2 Electricity use

We saw that fuel and heat in the sector Others, are largely consumed by residential buildings. For electricity, the consumption is more evenly spread over the sub sector “commerce and public services” and residential. Globally 49% of electricity is used in residential buildings and 41% in commerce and public services (also referred to as services). The use of electricity in the services sector strongly depends on the region and ranges from 17% in India to 56% in OECD Asia Oceania, see Figure 21.

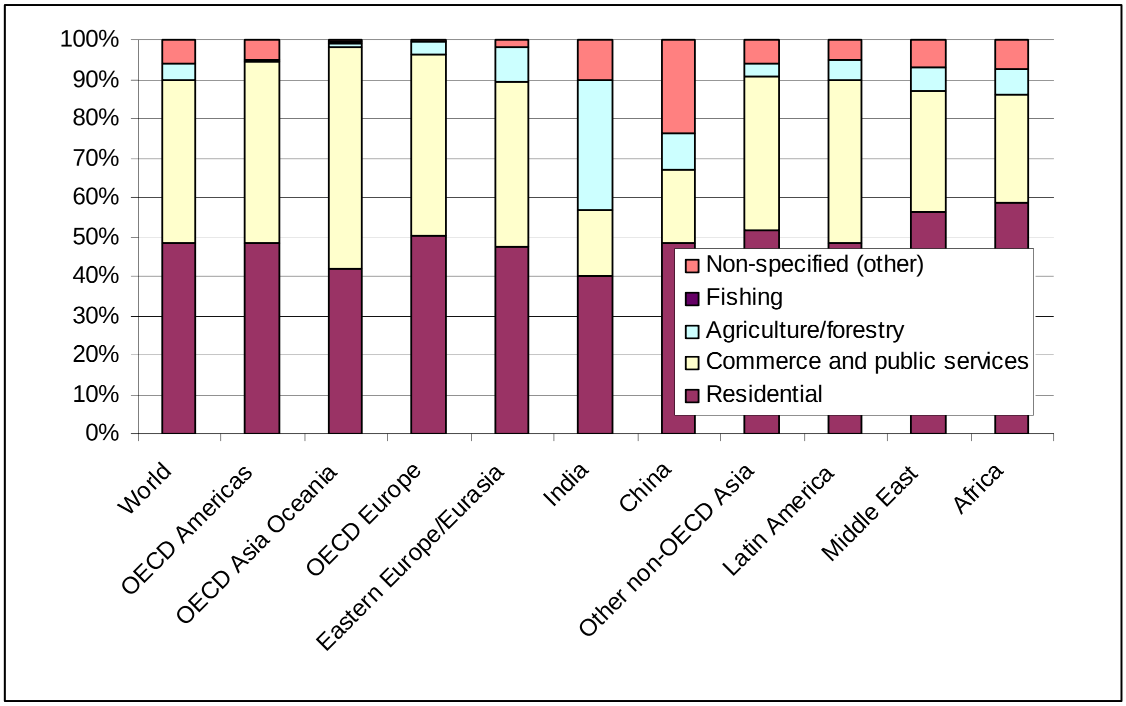

Figure 21 Breakdown of electricity use by sub sector in sector Others in 2009 (IEA, 2011b)

The breakdown of electricity use per type of appliance is different per region. In the [r]evolution scenario a convergence is assumed for the different types of electricity demand per region in 2050. Based on data in Table 17 and Table 18 in the appendix we come to the overall breakdown of electricity use per type (IEA (2009), IEA (2007) and IPCC (2007a)):

- Space heating 10%
- Hot water 10%
- Lighting 20%
- ICT and home entertainment (HE) 12%
- Other appliances 30%
- Air conditioning 18%

We will now discuss the energy savings options for electricity use in Others per type of application.

Space heating and hot water

Measures to reduce electricity use for space heating and hot water are similar to measures for heating by fuels (see section 3.1.1). Besides reducing the demand for heat by changing the building shell another option is to improve the conversion efficiency of heat supply. This can be done e.g. by the implementation of heat pumps. Heat pumps can provide both cooling and space and water heating. They use renewable energy[3] from their surroundings (ambient air, water or ground) and “high-grade” energy (e.g. electricity or natural gas) to raise the

[3] Depending on the way heat pumps are integrated in statistics they either save energy (e.g. reduce natural gas or electricity use) or they both reduce high grade energy use and simulaneously add to renewable energy use. In the latter case it may mean that total final consumption does not reduce, but there is only a shift. In IEA statistics the ambient heat of heat pumps is not taken into account and therefore they save energy rather than consume renewable energy. In this report therefore final energy consumption excludes ambient heat.

temperature for heating, or lower it for cooling. Their COP (coefficient of performance) value is typically in the range of 2.5-4. This means that they produce 2.5-4 times as much useful heat as the amount of high-grade energy input. In practice the design COP values are often not achieved and one talks about the SPF (Seasonal Performance Factor) which is about 10-20% below the COP value.
The sales of heat pumps in a number of major European markets experienced strong growth in recent years. Total annual sales in Austria, Finland, France, Germany, Italy, Norway, Sweden and Switzerland reached 576,000 in 2008, almost 50% more than in 2005 (IEA, 2010). Data suggest that heat pumps may be beginning to achieve a critical mass for space and water heating in a number of European countries.

Lighting

Incandescent bulbs have been the most common lamps for a more than 100 years. These lamps are the most inefficient type of lamps since up to 95% of the electricity is converted into heat (Hendel-Blackford et al., 2007). Incandescent lamps have a relatively short life-span (average value approximately 1000 hours), but have a low initial cost and optimal colour rendering. CFLs (Compact Fluorescent Light Bulbs) are more expensive than incandescent bulbs, but they use about 75% less energy and last about 10 times longer than standard incandescent bulbs (Energy Star, 2008). In the last years many policies have been implemented that reduce or ban the use of incandescent light bulbs.

The efficiency of lamps can be measured with the luminous efficacy. The luminous efficacy is a ratio of the visible light energy emitted (the luminous flux) to the total power input to the lamp. It is measured in lumens per watt (lm/W). The theoretical maximum efficacy possible is 240 lm/W for white light. The current best practice is 75 lm/W for fluorescent lights (future fluorescent lights are expected to give 100 lm/W) and 115 lm/W for white LEDs (future LEDs 150 lm/W) (UBA, 2009).

It is important to realise however that lighting energy savings are not just a question of using more efficient lamps, but also involves other approaches: reducing light absorption of luminaries (the fixture in which the lamp is housed), optimise lighting levels (levels in OECD countries commonly exceed recommended values (IEA, 2006)), use of automatic controls (turn off when no one is present, dim artificial light in respond to rising daylight), retrofitting buildings to make better use of daylight. Buildings designed to optimize daylight can receive up to 70% of their annual illumination needs from daylight and while a typical building will only get 20 to 25% (IEA, 2006).

The IEA publication Light's Labour's Lost (2006) projects that the cost-effective savings potential from energy efficient lighting in 2030 is at least 38% of lighting electricity consumption, disregarding newer and promising solid state lighting technologies such as light emitted diodes (LEDs).

ICT and HE equipment

ICT (information and communication technologies) and home entertainment consist of a growing number of appliances in both residential and commercial buildings, such as computers, (smart) phones, televisions, set-top boxes, games consoles, printers, copiers and servers. ICT and consumer electronics account for about 15% of residential electricity consumption now (IEA, 2009b). Globally a rise of 3 times is expected for ICT and consumer electronics, from 776 TWh in 2010 to 1700 TWh in 2030. One of the main options for reducing energy use in ICT and HE equipment is using best available technology. IEA (2009b) estimates that a reduction is possible from 1700 TWh to 775 TWh in 2030 by applying best available technology and to 1220 TWh by least life-cycle costs measures, which do not impose additional costs on consumers. Below we discuss other energy savings options for ICT and HE equipment.

Power management

An automated software program makes it possible to put a device in standby mode or shut it down completely, at a given time or after a period of inactivity. This ensures that the device uses less energy over day and are completely off during the night, which saves much energy. Bray (2006) states that studies have shown that automatic and/or manual power management of computers and monitors can significantly reduce their energy consumption. A power managed computer consumes less than half the energy of a computer without power management (Webber et al., 2006), and depending on how your computers are used, power management can reduce the annual energy consumption of your computers and monitors by 80% (Webber et al., 2006). Approximately half of all office computers are left on overnight and on weekends (75% of the week), so all computers should be turned off at night. Further savings can be made by ensuring computers enter low power mode when they are idle during the day (Bray, 2006). An added benefit of decreasing the power consumption of computers and monitors is an indirect effect. In addition to the direct contribution of computer and monitors to office energy consumption, they also increase the load on air conditioning. According to a study by Roth et al (2002), office equipment increases the load on air conditioning by 0.2-0.5 kW per kW of office equipment power drawn.

Replace CRT screens

Some computers and televisions in residential and services sector still work with a CRT screen. A CRT screen uses more energy than a flat screen. A 17 inch LCD has a considerably lower power usage than a CRT and requires around 35 Watts while the 17 inch CRT requires around 90 W. A similar situation holds for the 19 inch LCD which requires around 45 watts while the 19 inch CRT requires around 110 watts (Bootstrike, 2008).

Also old CRT-based TVs are relatively inefficient; however, since CRT screen size is limited, they don't always use more power than larger flat-screen models. For TVs a 46 inch LED screen uses between 64 and 142 W versus 100-150 W for LCD and 280-330 W for a plasma TV (CNET, 2012). So when buying a new TV, LED or LCD screens are preferred to plasma screens.

Efficient servers

The growing use of all types of internet services implied a strong growth of servers and data centers worldwide. Data centres are facilities that primarily contain electronic equipment used for data processing, data storage, and communications networking (US EPA, 2007a). About 80% of all servers are located in these types of data centres (Fichter, 2007).

Typical component peak power breakdown for servers is given in Figure 22.

Component	Peak Power (Watts)
CPU	80
Memory	36
Disks	12
Peripheral slots	50
Motherboard	25
Fan	10
PSU losses	38
Total	251

Figure 22 Component peak power breakdown for a typical server (Fan et al., 2007, US EPA, 2007a). PSU = power supply unit

The installed base of servers keeps growing rapidly due to increasing demand for data processing and storage. New digital services (like music downloads, video-on-demand, online banking, electronic trading, satellite navigation, Internet telephony) spur this rapid growth, as well as increasing penetration of computers and Internet in developing countries. Since systems become more and more complex to handle increasingly large amounts of data, power and energy consumption (about 50% used for cooling) grow along (US EPA, 2007a). Aggregate electricity use for servers doubled over the period 2000 to 2005 both in the US and worldwide (Koomey, 2007), see Figure 23. Data centres consumed roughly 0.8% of global electricity use in 2005 (125 TWh) (Koomey, 2007). As a comparison, JRC (2008) estimate an EU-wide electricity use for data centres of around 56 TWh in 2007, which could grow to 104 TWh in 2020 (Bettgenhauser et al., 2009).

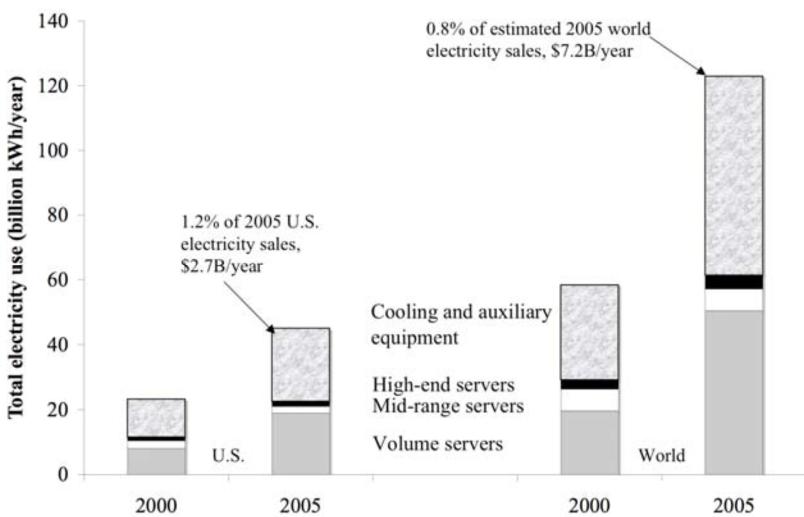

Figure 23 Total electricity use for servers in the U.S. and the world in 2000 and 2005, including the associated cooling and auxiliary equipment (Koomey, 2007)

Power and energy consumption are key concerns for data centres (Bianchini and Rajamony, 2004). There is a significant potential for energy-efficiency improvements in data centres. Existing technologies and design strategies have been shown to reduce the energy use of a typical server by 25% or more (US EPA, 2007a). Energy-management practices in existing data centres could reduce current data centre energy usage by around 20% (US EPA, 2007a).

The US EPA state-of-the-art scenario (measures: adopt energy efficient servers, enable power management on all servers and other equipment, consolidate servers and storage, liquid cooling instead of air cooling, improve efficiency chillers, pumps, fans, transformers, and use combined heat and power; for more measures see US EPA (2007a)) could reduce electricity use by up to 56% compared to current trends.

Set-top boxes

Set-top boxes (STBs) are used to decode satellite or cable television programmes and are a major new source of energy demand. More than a billion are projected to be purchased worldwide over the next decade (IEA, 2006b). The energy use of an average set-top box is 20-30 W, but it uses nearly the same amount of energy when switched off (IEA, 2009; Horowitz, 2007). In the US, STB energy use is estimated at 15 TWh/year or about 1.3% of residential electricity use (Rainer et al., 2004).

According to Horowitz (2007), cable/satellite boxes without digital video recorders (DVRs) use 100 to 200 kWh of electricity per year. High definition cable and satellite boxes use only slightly more energy on average. Cable and satellite set-top boxes with DVRs use between 200 and 400 kWh per year. Media receiver boxes use less energy (around 35 kWh per year) but must be used in conjunction with existing audiovisual equipment and computers, thus adding another 35 kWh to the annual energy use of existing home electronics. Figure 24 shows annual energy use of common household appliances. The figure shows that the energy use of some set-top boxes approaches that of the major energy consuming household appliances.

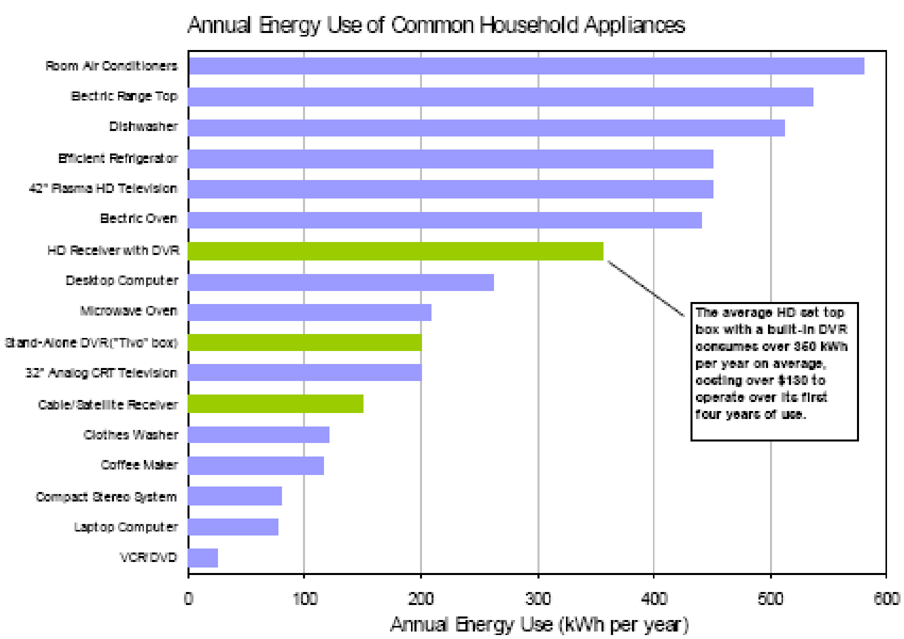

Figure 24 Annual energy use of common households appliances (Horowitz, 2007).

Reducing the energy use of set-top boxes is complicated by their complex operating and communication modes. Although improvements in power supply design and efficiency will be effective in reducing energy use, the major energy savings will be obtained through energy management measures (Rainer et al., 2004). Rainer et al (2004) reports a savings potential between 32% and 54%.

Non-office hours

In the service sector electricity can be saved by reducing use during non-office hours. Offices are used on average for 2000 hours per year. After office hours, approximately 25% of the electricity is still used by fans, computers in standby mode, printers and faxes, etc., compared to the electricity used during office hours. By applying rather simple measures such as installing a time switch and monitoring the energy use of the office building, roughly 27% of the electricity used in offices can be saved (Harmelink and Blok, 2004).

Other appliances

Other appliances include e.g. cold appliances, washing machines, dryers, dish washers, ovens and other kitchen equipment. Cold appliances refer to both freezers and refrigerators. Electricity use for cold appliances depends on average per household storage capacities, the ratio of frozen to fresh food storage capacity, ambient temperatures and humidity, and food storage temperatures and control (IEA, 2003). European households typically either have a refrigerator-freezer in the kitchen (sometimes with an additional freezer or refrigerator), or they have a refrigerator and a separate freezer. Practical height and width limits place constraints on the available internal storage space for an appliance. Similar constraints apply in Japanese households, where ownership of a single refrigerator-freezer is the norm, but are less pressing in OECD North America and Australia. In these countries almost all households have a refrigerator-freezer and many also have a separate freezer and occasionally a separate refrigerator (IEA, 2003). Bettgenhauser et al. (2009) estimate that by improving the energy-efficiency of cold appliances on average 45% of electricity use could be saved for EU-27. For “wet appliances” they estimate a potential of 40-60% savings by implementing best practice technology (see Table 3).

Table 3 Reference and best practice electricity use by „wet appliances“ (Bettgenhauser et al., 2009)

Washing machine*	
Reference (kWh/dwelling/yr)	231
Best practice (kWh/dwelling/yr)	116
Improvement (%)	50
Dryers*	
Reference (kWh/dwelling/yr)	440
Best practice (kWh/dwelling/yr)	210-140
Average Improvement (%)	60
Dish washers *, **	
Reference -2005 (kWh/dwelling/yr)	305
Best practice (kWh/dwelling/yr)	209-163
Average Improvement (%)	40

* www.milieucentraal.nl
** estimate of 163 derived from VHK, 2005

Air conditioning

There are several options for technological savings from air conditioning equipment; one is using a different refrigerant. Tests with the refrigerant Ikon B show possible energy consumption reductions of 20-25% compared to regularly used refrigerants (US DOE EERE, 2008).

Also geothermal cooling is an important option. This uses the same principle as geothermal heating, namely that the temperature at a certain depth in the Earth remains constant year-through. In the winter we can use this relatively high temperature to warm our houses. Conversely, we can use the relatively cold temperature in the summer to cool our houses. There are several technical concepts available, working with either one or two storage reservoirs or with heat exchangers underground. Most energy savings can be achieved with two storage reservoirs in aquifers where in summer time cold water is used from the cold reservoir. The hot reservoir can be used with a heat pump for heating in winter.

Solar energy can also be used for heating and cooling. Solar cooling is the use of solar thermal energy or solar electricity to power a cooling appliance. Basic types of solar cooling technologies are: absorption cooling (uses solar thermal energy to vaporize the refrigerant); desiccant cooling (uses solar thermal energy to regenerate (dry) the desiccant); vapour compression cooling (use solar thermal energy to operate a Rankine-cycle heat engine); evaporative cooling; and heat pumps and air conditioners that can be powered by solar photovoltaic systems (Darling, 2005). To drive the pumps only 0.05 kW of electricity is needed (instead of 0.35 kW for regular air conditioning)[4] (Austrian Energy Agency, 2006).

Not only is it important to use efficient air conditioning equipment, it is as important to reduce the need for air conditioning. Important ways to reduce cooling demand are: use insulation to prevent heat from entering the building, reduce the amount of inefficient appliances present

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[4] Note that solar cooling and geothermal cooling may reduce the need for high grade energy such as natural gas and electricity. On the other hand they increase the use of renewable energy. The energy savings achieved by reducing the need of high grade energy will be partly compensated by an increase of renewable energy.

in the house (such as incandescent lamps, old refrigerators, etc.) that give off heat, use cool exterior finishes (such as cool roof technology (US EPA, 2007), or light-coloured paint on the walls) to reduce the peak cooling demand (as much as 10-15% according to ACEEE (2007)), improve windows and use vegetation to reduce the amount of heat that comes into the house, and use ventilation instead of air conditioning units. An example of an alternative to cooling a whole house or building was developed by the company Evening Breeze (Evening Breeze, 2008). They combined a mosquito net, bed and air conditioning such that only the bed has to be cooled instead of the entire bedroom.

3.1.3 Energy savings in low energy demand scenarios Others

Two scenarios are available that include a reduction of future energy demand in buildings for the IEA regions, in comparison to reference levels. These are the WEO 450 ppm scenario (IEA, 2011a) and the IEA Blue map scenario (IEA, 2010). The 450 ppm scenario is based on implementation of new policies on top of current policies in the period up to 2035. In this scenario in 2035 the following is achieved:

- China: 100% of buildings stock has improved insulation to reduce energy consumption per unit area by 65% vs. 1980 level. 50% of appliances stock meets highest-available efficiency standards.
- US: More stringent mandatory building codes. Extension of energy efficiency grants. Zero-energy buildings initiative.
- EU: Enhanced efficiency standards for existing buildings. Zero-carbon footprint for all new buildings as of 2018.
- India: Mandatory energy conservation standards and labelling requirements for all equipment and appliances. Increased penetration of energy efficient lighting.
- Russia: mandatory building codes by 2030 and phase out inefficient lighting equipment and appliances by 2030.

Table 4 shows the annual reduction of energy demand in the 450 ppm scenario in the period 2015 to 2035 in comparison to the WEO current policies scenario.

Table 4 Annual reduction of energy demand in sector Others in 450 ppm scenario in comparison to current policies scenario (IEA, 2011a)

	Reduction in %/yr for period 2015-2035 in 450 ppm scenario[5]	
	Fuel/heat	Electricity
OECD Americas	0.1%	0.7%
OECD Asia Oceania	0.3%	1.0%
OECD Europe	0.6%	0.8%
Eastern Europe/Eurasia	1.1%	1.4%
India	0.6%	1.4%
China	0.3%	2.2%
Other non-OECD Asia	0.2%	1.0%
Latin Americas	0.3%	1.0%
Middle East	0.9%	1.2%
Africa	0.2%	0.8%
World	**0.3%**	**1.3%**

In the BLUE Map scenario (IEA, 2010), energy consumption in the buildings sector is reduced by around one-third of the baseline scenario level in 2050 (1.2 %/yr reduction in period 2015-2050 in comparison to baseline level in 2050). This means that energy consumption in 2050 is only 5% higher than in 2007, despite an increase in households of 67% and in service sector floor area of 195% over that time.

The level of energy savings and the percentage reduction below the Baseline vary significantly between regions. The largest percentage reductions occur in China (38%), the economies in transition (38%) and OECD Europe (37%). China's reduction in 2050 is a result of both improved efficiency and switching away from the inefficient use of traditional biomass in buildings to modern bioenergy (biofuels, biogas and bio-dimethyl ether) and commercial fuels. The smallest percentage reduction below the Baseline occurs in India and is due to a rebound effect in which some increased consumption is triggered by some of the energy efficiency measures in the period to 2050. The largest absolute reductions occur in China, OECD Europe and OECD North America. Figure 25 shows which types of energy use have the highest share in the savings in the BLUE Map scenario.

[5] In comparison to current policies scenario

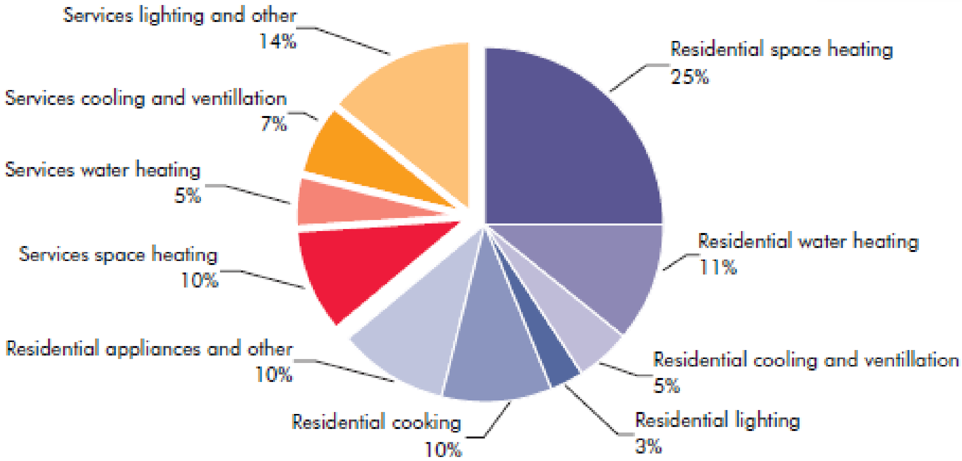

Figure 25 Breakdown of energy savings in BLUE Map scenario for sector Others (IEA, 2010)

Table 5 shows the annual reduction of energy demand in the Blue map scenario in the period 2015 to 2035 in comparison to its reference scenario.

Table 5 Annual reduction of energy demand in buildings in IEA BLUE Map scenario in comparison to its reference scenario (IEA, 2010)

	Relative energy savings in %/yr for period 2015-2050[6]	
	Fuel/heat	Electricity
OECD Americas	0.9%	1.1%
OECD Asia Oceania	0.7%	0.8%
OECD Europe	1.6%	1.1%
Eastern Europe/Eurasia	1.6%	0.9%
India	0.5%	1.0%
China	1.4%	1.4%
Other non-OECD Asia	0.4%	0.9%
Latin America	0.8%	0.6%
Middle East	1.6%	1.0%
Africa	1.4%	0.5%
World	**1.3%**	**1.0%**

The BLUE Map scenario is based on the large-scale deployment of a wide number of technology options for the buildings sector, including:

- Tighter building standards and codes for new residential and commercial buildings. Regulatory standards for new residential buildings in cold climates are tightened to

[6] In comparison to reference scenario

between 15 and 30 kWh/m^2/year for heating purposes, with little or no increase in cooling load. In hot climates, cooling loads are reduced by around one-third. For commercial buildings, standards are introduced which halve the consumption for heating and cooling compared to 2007. This will enable the downsizing of heating and cooling equipment.

- Large-scale refurbishment of residential buildings in the OECD. Around 60% of residential dwellings in the OECD which will still be standing in 2050 will need to be refurbished to a low-energy standard (approximately 50 kWh/m^2/ year), which also enables the downsizing of heating equipment. This represents the refurbishment of around 210 million residential dwellings in the OECD between 2010 and 2050.
- Highly efficient heating, cooling and ventilation systems. Heating systems need to be both efficient and cost-effective. The coefficient of performance (COP) of installed cooling systems doubles from today's level.
- Improved lighting efficiency. Notwithstanding recent improvements, many driven by policy changes, there remains considerable potential to reduce lighting demand worldwide through the use of the most efficient options.
- Improved appliance efficiency. Appliance standards are assumed to shift rapidly to least life-cycle cost levels, and to the current BAT levels by 2030.
- The deployment of heat pumps for space and water heating. This occurs predominantly in OECD countries, and depends on the relative economics of different abatement options. And the deployment of micro- and mini-CHP for space and water heating, and electricity generation.

The energy [r]evolution scenario in the sector others is based on a combination of the 450 ppm scenario, the Blue map scenario and other assumptions. We assume that policies to improve energy-efficiency in Others are implemented in 2013 and will lead to energy savings from 2014 onwards. Table 6 shows the annual reductions of energy demand in Others in comparison to the reference scenario.

For electricity use in OECD countries we use savings potentials as calculated in the SERPEC-CC study for EU-27 (Bettgenhäuser et al. 2009). In this study potentials have been calculated for energy savings from all types of energy-efficiency improvement options. This bottom-up study estimated a savings potential of 2.5% per year for electricity use in buildings in comparison to frozen technology levels, for a 25 year period. We assume that this annual efficiency improvement rate can be achieved in OECD countries for the period 2013-2050. As mentioned in section x, we assume that autonomous energy-efficiency improvement in the reference scenario equals 1% per year. This means that in addition to the reference scenario electricity savings amount to 1.5% per year in OECD countries. This potential for electricity use in OECD countries is within the technical potentials for electricity savings as calculated by Graus et al. (2011), which gives a technical potential of 3% per year for electricity use in buildings against frozen technology level.

Table 6 Annual reduction of energy demand in sector Others in Energy [R]evolution scenario in comparison to the corresponding reference scenario

	Energy [R]evolution – energy savings in %/yr period 2013-2050[7]		450 ppm scenario %/yr[8]		Blue map - energy savings in %/yr[9]	
	Fuel/heat	Electricity	Fuel/heat	Electricity	Fuel/heat	Electricity
OECD Americas	0.4%	1.5%	0.1%	0.7%	0.9%	1.1%
OECD Asia Oceania	0.8%	1.5%	0.3%	1.0%	0.7%	0.8%
OECD Europe	1.6%	1.5%	0.6%	0.8%	1.6%	1.1%
Eastern Europe/Eurasia	1.6%	0.9%	1.1%	1.4%	1.6%	0.9%
India	0.6%	0.6%	0.6%	1.4%	0.5%	1.0%
China	0.4%	1.4%	0.3%	2.2%	1.4%	1.4%
Other non-OECD Asia	0.4%	1.0%	0.2%	1.0%	0.4%	0.9%
Latin Americas	0.8%	1.0%	0.3%	1.0%	0.8%	0.6%
Middle East	0.9%	1.0%	0.9%	1.2%	1.6%	1.0%
Africa	1.0%	0.5%	0.2%	0.8%	1.4%	0.5%
World	**0.9%**	**1.3%**	**0.3%**	**1.3%**	**1.3%**	**1.0%**

Table 7 shows the final energy consumption in absolute values for the energy [r]evolution scenario, the BLUE Map scenario and 450 ppm scenarios as comparison. Table 8 shows the underlying reference scenarios for all three scenarios.

Table 7 Global final energy consumption for sector Others (EJ) in 2030 and 2050

	2030			2050		
	Heat/fuels	Electricity	Total	Heat/fuels	Electricity	Total
Energy [r]evolution	92.8	47.4	140.2	85.8	52.3	138.1
IEA Blue map	76.6	42.0	118.6	73.2	52.4	125.4
IEA WEO - 450 ppm scenario	97.7	49.8	147.5	-	-	-

Table 8 Global final energy consumption for sector Others (EJ) in 2030 and 2050 in underlying baseline scenarios

	2030			2050		
	Heat/fuels	Electricity	Total	Heat/fuels	Electricity	Total
Reference scenario - Energy [r]evolution	107.6	58.8	166.4	118.5	81.2	199.7
Reference scenario - BLUE Map	96.1	53.2	149.3	107.6	76.9	184.5
IEA WEO – current policies scenario	108.0	59.0	167.0	-	-	-

It should be noted that the BLUE Map scenario for buildings covers a lower share of the energy demand than the sector Others in the Energy [R]evolution scenario and in the IEA WEO scenario; about 90% of energy demand. Still it becomes clear that the Energy [R]evolution scenario for the sector Others is slightly below the 450 ppm scenario and reasonably in line with the IEA BLUE Map scenario, in terms of the level of energy demand.

[7] In comparison to reference scenario (extrapolated WEO current policies scenario)
[8] In comparison to WEO current policies scenario
[9] In comparison to BLUE Map reference scenario

3.2 Industry

Figure 26 gives the reference scenario for final energy demand in industries in the period 2009-2050.

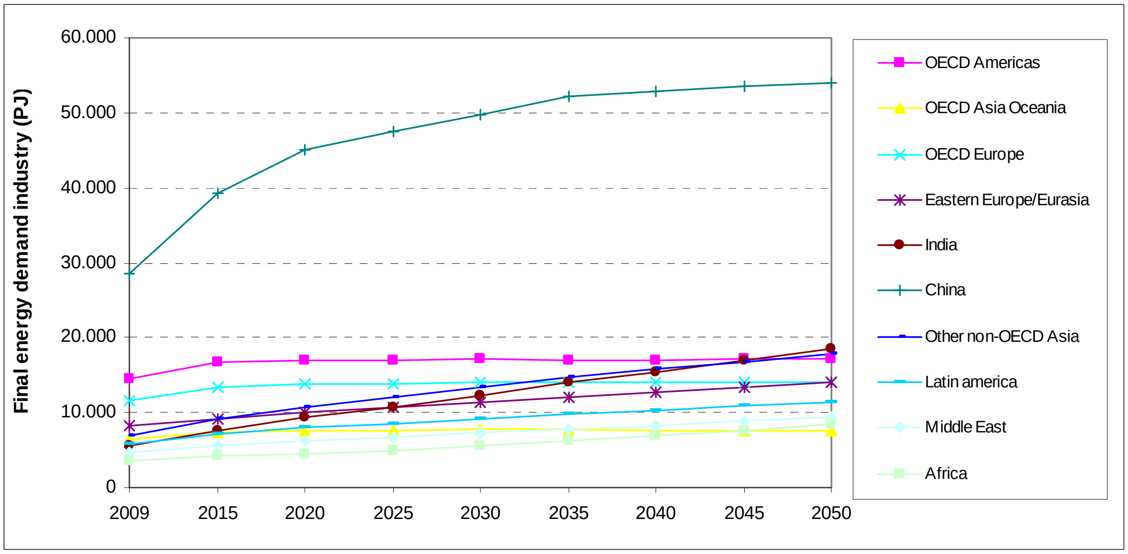

Figure 26 Projection of industrial energy demand in period 2009-2050 per region

As can be seen, the energy demand in Chinese industries is expected to be huge in 2050 and amount to 54 EJ. The energy demand in all other regions together is expected to be 118 EJ, meaning that China accounts for 31% of worldwide energy demand in industries in 2050.

Figure 27 shows the share of industrial energy use in total energy demand per region for the years 2009 and 2050.

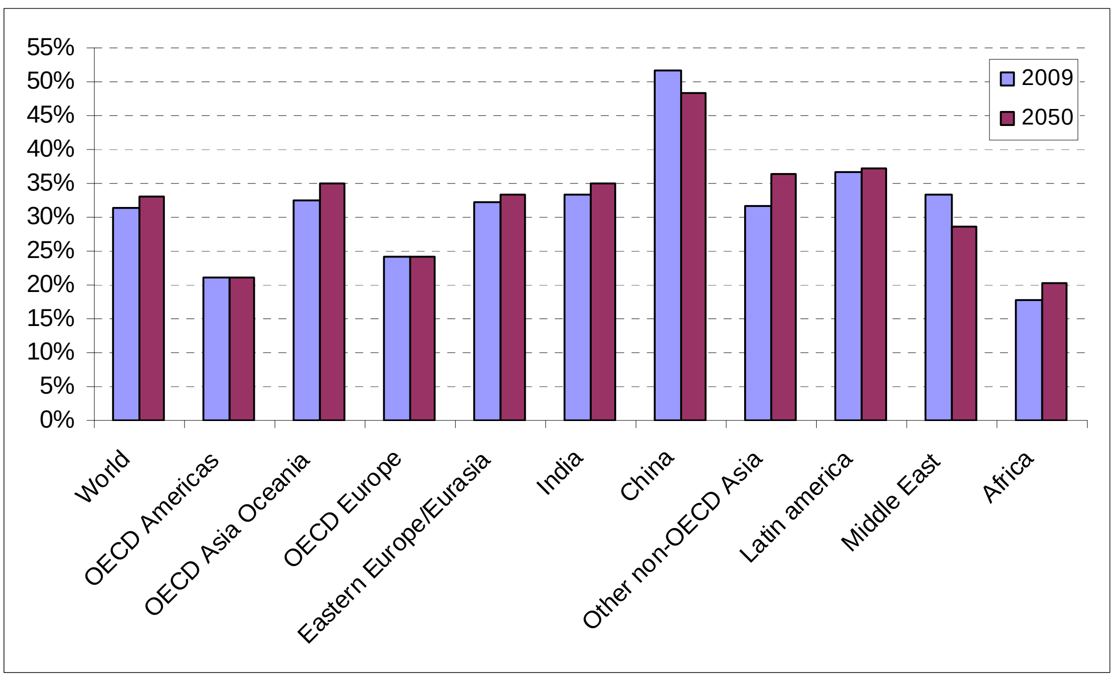

Figure 27 Share industry in total final energy demand per region in 2009 and 2050

The worldwide average share of industry in total final energy demand is about 30%, both in 2009 as in 2050. The share in Africa is lowest with 20% in 2050. The share in China is highest with 48% in 2050.

Figure 28 shows a breakdown of final energy demand by sub sector in industry worldwide for the base year 2009.

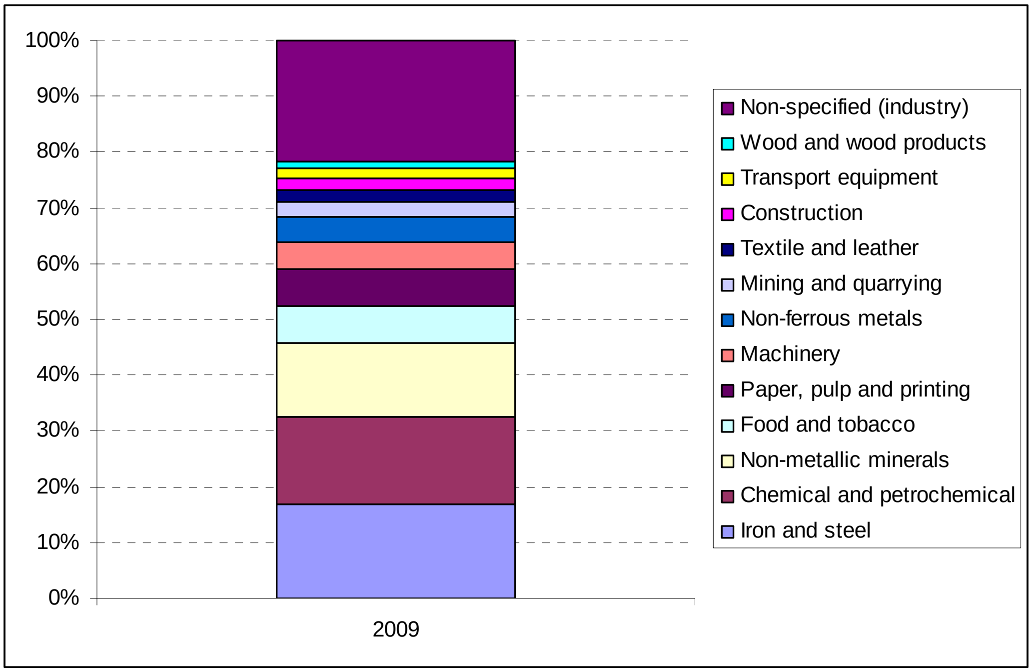

Figure 28 Breakdown of final energy consumption in 2009 by sub sector for industry (IEA, 2011b)

The largest energy consuming sectors in industry are chemical and petrochemical industry, iron and steel and non-metallic minerals. Together the sectors consume about 50% of industrial energy demand. Since these three sectors are relatively large we look at them in detail. Also we look at aluminium production in detail, which is part of the category non-ferrous metals. This is because the share of aluminium production in total industrial power demand is quite large, corresponding to nearly 11% in 2009 (IEA, 2011b). For all sectors we look at implementing best practice technologies, increased recycling and increased material efficiency. Where possible the potentials are based on specific energy consumption data in physical units (MJ/tonne steel, MJ/tonne aluminium etc.).

Iron and steel

The iron and steel industry is mainly 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).

In the figure below you can see the share of steel production per region by technology. The basic oxygen furnace is most often used and accounts for 71% of worldwide steel production. The share of open hearth furnace is very small and only used on a larger scale in the region “Transition Economies”. Open hearth furnace is an older and less efficient technology for producing steel than basic oxygen furnaces. The share of electric steel in total steel production accounts for around 28% of worldwide steel production in 2009.

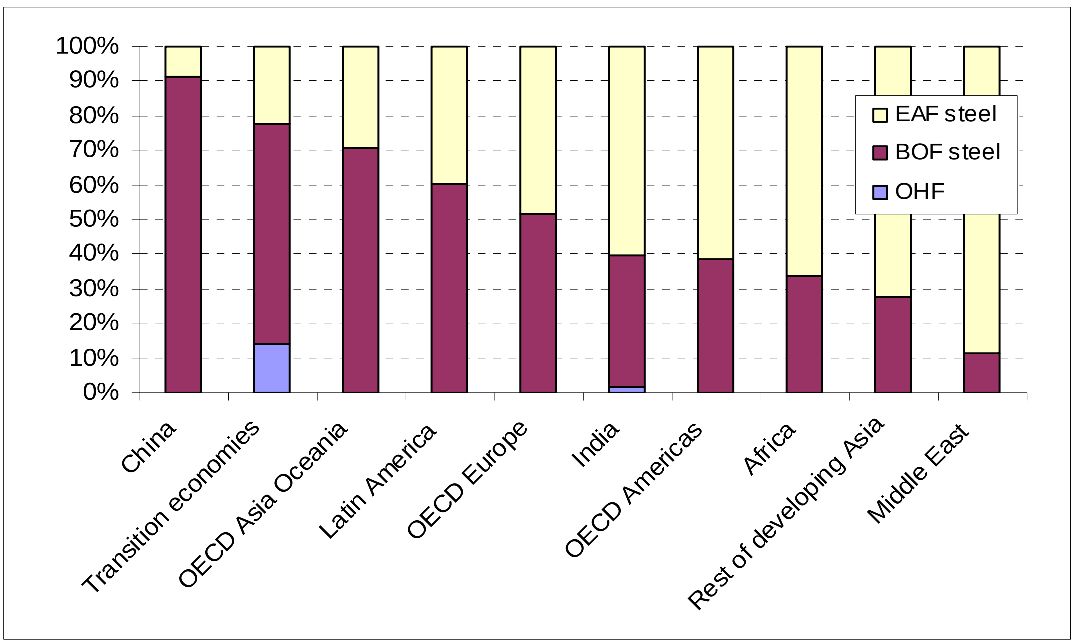

Figure 29 Steel production per region by technology in 2009 (based on IISI, 2011)

Two types of iron production can be discerned, pig iron (produced in blast furnaces) and direct reduced iron (DRI). In the figure below you can see the share of iron production per region by technology. The share of direct reduced iron is still small. Worldwide it is used for 6% of total iron production. The application differs strongly per region. The Middle East the technology is most often applied.

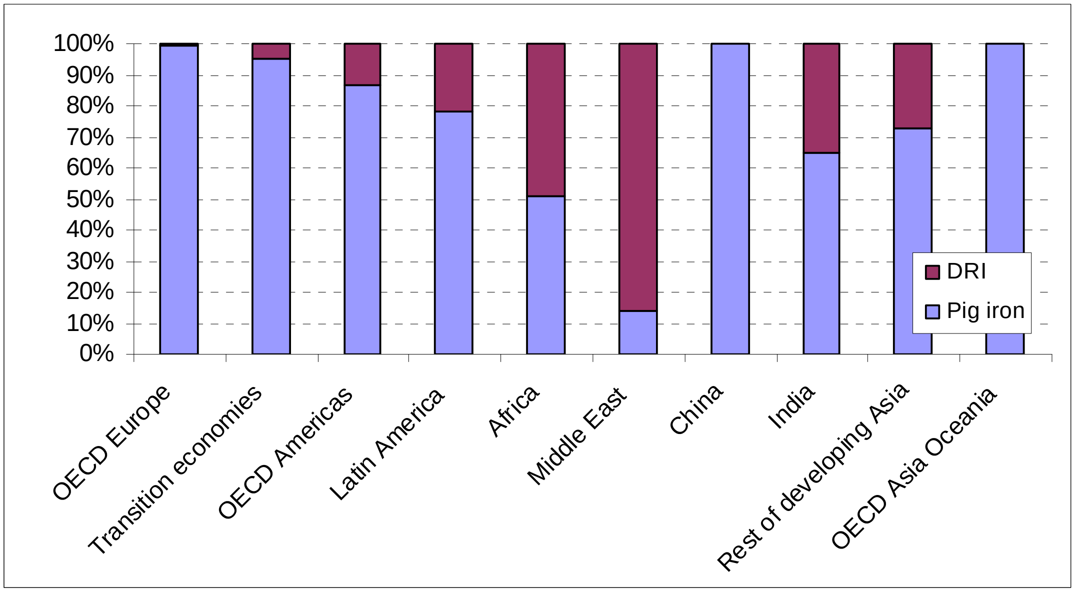

Figure 30 Iron production per region by technology in 2009 (based on IISI, 2011)

Figure 31 shows specific energy consumption for iron and steel production by region in 2009 and in the reference scenario in 2050. The specific energy consumption in 2050 is based on an energy-efficiency improvement in the reference scenario of 1% per year (see section 2.1 for more details regarding energy-efficiency improvement in the reference scenario). The specific energy consumption in 2009 is based on final energy demand of the iron and steel sector in IEA Energy Balances 2009 and the total crude steel production by region in 2009 reported in the IISI Statistical Yearbook 2011. The Middle East is excluded in the figure due to data unreliability.

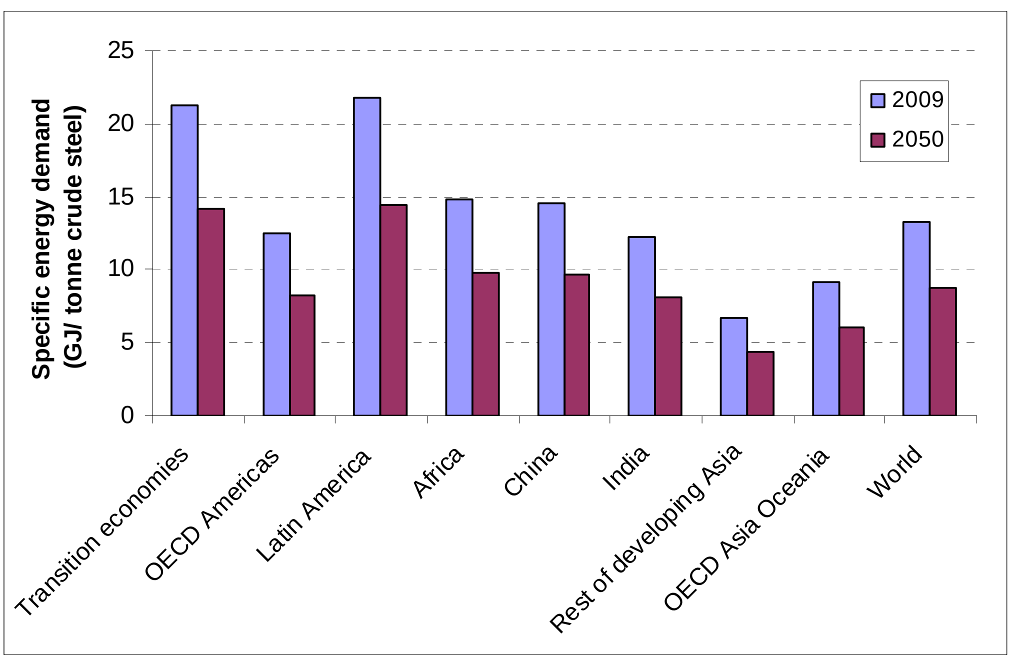

Figure 31 Specific final energy consumption (GJ/tonne steel) in reference scenario

The energy-efficiency for iron and steel production is influenced by the technologies used and the amount of scrap input. 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 9 shows the current best practice specific energy consumption for steel production.

Table 9 Best practice final energy consumption for iron and steel production [Kim and Worrell (2002), IISI (1998), IEA (2006) and Worrell et al., 2008 for current best practice and Fruehan et. al (2000) for theoretical and practical minimum]

Product	Specific final energy consumption (GJ/tonne steel)			
	Current global average	**Current best practice**	**Theoretical minimum (practical minimum)**	**Estimated best practice in 2030**
Primary steel production in basic oxygen furnace (BOF) excluding transformation losses in blast furnace and coke production[10]	10	6.4	1.3 (1.6)	4.3
Steel production in electric arc furnace (EAF) with scrap input	2.2	1.6	1.3 (1.6)	1.6
Direct reduction processes	N/A	5	N/A	3.3
Smelting reduction processes	N/A	6.1	N/A	4.1
Continuous casting	N/A	0.1	N/A	
Hot rolling	2.2	1.7	0.03 (0.9)	1.1
Cold rolling	1.2	0.4	0.02 (0.02)	0.1
Thin slab near/near net shape casting	N/A	0.2	N/A	0.1

There are two main ways for reducing final energy consumption in the iron and steel industry which are implementing best practice technologies and increased recycling.

We assume the average energy consumption of iron and steel plants in 2050 can be equal to the best practice in 2030. This is based on an average life time of industrial plants of 30 years and a continuous improvement of best practice technologies. The best practice in 2030 is based on 2% per year energy-efficiency improvement of best practice technologies. An exception is made for EAF, where current best practice is equal to practical minimum. Another exception is made for cold rolling, where best practice is estimated to be lower due to low practical minimum in comparison to current best practice.

The energy-intensity for recycled steel is around 70-75% lower than the energy-intensity for

[10] In IEA statistics final energy consumption in the iron and steel sector excludes transformation losses occuring in blast furnaces and coke ovens. These losses amount to 6.5 GJ per tonne of steel in 2009 (based on IEA, (2011b) and IISI (2011)).

primary steel. Increasing the amount of recycled steel is therefore an important energy savings option. Currently 36% of all crude steel production is derived from scrap (IEA, 2009). The potential for recycling steel depends on the availability of scrap. Neelis and Patel (2006) estimate the potential for the share of scrap in total steel production to be between 60-70% by 2100. We assume that the amount of recycled steel in total steel production can be 60% in 2050.

For steel casting, a continuous or a thin slab/near net shape casting system can be used. Thin slab casting is a more advanced technology than continuous casting. In thin slab casting steel products are cast closer to the shape of the final product therefore reducing the need for hot rolling (Worrell et al., 2008).

Together with the best practice values for steel production in 2030 this leads to a specific final energy consumption for iron and steel production of 3.0 GJ/tonne crude steel by 2050 in all regions[11]. This is based on the following assumptions:

- 60% of the steel is produced from scrap in EAF furnaces
- 20% of steel is produced in blast furnace - BOF combination
- 20% of steel is produced by direct reduction process
- 66% (70% of the 94% of the hot rolled steel share in 2009) of the steel production is cast in thin slab casting systems
- 28% (30% of the 94% of the hot rolled steel share in 2009) is hot rolled
- 74% of the steel is also cold rolled.

The practical minimum specific energy consumption for iron and steel production, based on the above assumptions, is 2.0 GJ/tonne crude steel. Therefore, after 2050, energy-efficiency could further be reduced by 35%.

[11] For the Middle East we assume no energy savings since data for specific energy consumption is already very low.

Non-metallic minerals

Non-metallic minerals include cement, lime, glass, soda, ceramics, bricks and other materials. Since cement accounts for about 85% of total energy use in the production of non-metallic minerals (IEA, 2009), in this paragraph we discuss specifically the energy-efficiency of cement production.

Two important processes in producing cement are clinker production and the blending of clinker with additives to produce cement. Clinker is produced by burning a mixture of mainly limestone ($CaCO_3$), silicon oxides, aluminium oxides and iron oxides in a kiln. Production can take place in the wet process, the dry process and some intermediate forms (referring to the conditions of raw materials processing). The dry process is more energy-efficient than the wet process. After the melt has cooled down, clinker is blended with gypsum and (depending on the desired product) fly ash, blast furnace slag, or other additives. Product qualities depend on the relative amount of clinker in the cement (ranging from 95% in Portland cement to 30% for blast furnace cement). Clinker production is the most energy intensive step in cement production. The current state of the art kilns consume 2.9-3.3 GJ/tonne clinker of fuel (IEA, 2009). The thermodynamic minimum is 1.8 GJ/tonne clinker, but strongly depends on the moisture content. The current typical thermal energy use for cement production in different countries ranges between 3.2 and 4.5 GJ/tonne clinker (IEA, 2009). Substantial energy savings can be obtained by reducing the amount of clinker required. One option to reduce clinker use is by substituting clinker by industrial by-products such as coal fly ash, blast furnace slag or pozzolanic materials (e.g. volcanic material). The relative importance of additive use can be expressed by the clinker to cement ratio. The clinker to cement ratio for current cement production ranges from 25-99% (UBA, 2009), with the average ratio in 2009 at 76% (WBCSD/CSI, 2009).

The energy use for cement production can be reduced by implementing best practice technologies and by reducing the clinker content in cement. In 2009, the global average specific energy consumption equals 3.2 GJ per tonne cement and 3.7 GJ per tonne clinker (WBCSD/CSI, 2009). The average clinker to cement ratio equals 76% and the average electricity consumption for grinding of 110 kWh per tonne cement (WBCSD/CSI, 2009).

We assume that the specific energy consumption for cement production can be reduced to 2.1 GJ/tonne cement in 2050, based on implementation of best practice technology (2.8 GJ/tonne clinker and 56 kWh/tonne cement on average in 2050) and reduction of clinker content (from 76% in 2009 to 70% in 2050). The decline of clinker content to 70% is also used from IEA in the estimation of their Blue Scenarios (IEA, 2009). The adoption of BAT and the reduction in clinker content from 76% to 70% will result in a reduction of specific energy use of 33%.

We apply that the energy-efficiency improvement potential for cement production to the total non-metallic minerals sector.

Recycling of aluminium

Aluminium can either be produced from bauxite ore (primary aluminium production) or scrap (secondary aluminium production). In primary aluminium production, bauxite ore is refined into alumina through the Bayer process, where crushed bauxite is dissolved into a mix of sodium hydroxide and sodium carbonate (digestion). Oxides and other impurities are then removed (“red mud”) and the solution is precipitated and then calcined in rotary or fluidized bed kilns to produce alumina. Alumina refining is a highly energy consuming process. About 85% of energy use is fuel and 13% electricity (Worrell et al., 2008). According to the International Aluminium Institute (IAI, 2011), in 2009 the energy use in the various world regions ranged between 9.3 and 16.8 GJ/tonne alumina.

The production of primary aluminium from alumina (aluminium smelting) is the most energy intensive step in primary aluminium production. Aluminium is produced by passing a direct current through a bath with alumina dissolved in a molten cryolite electrode. According to the IAI (2011), in 2009 electricity intensity in the various world regions ranged between 14.4 and 15.7 MWh/tonne aluminium. It is estimated that in 2009 aluminium smelting was responsible for approximately 8% of the world industrial electricity use.

Secondary aluminium production uses only 5% 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.

Around 18 million tonnes of aluminium was recycled in 2007 worldwide, which fulfilled around 32% of the global demand for aluminium (56 million tonnes) (GARC, 2009). Nowadays, aluminium production from old scrap comes from transport (42%), packaging (28%), engineering and cables (11%), and building applications (8%). Recycling rates for building and transport applications range from 60-95% in various countries. Recycling rates can be further increased e.g. by improved recycling of aluminium cans. In Sweden, 91% of aluminium cans are recycled and in Switzerland 90%. The European average is however only 50% (GARC, 2009).

We assume that by 2050, 40% 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 38% of the electricity consumption for aluminium production (assuming secondary aluminium uses 5% of the energy demand for primary production) and 40% of the energy consumption for alumina production as the demand for alumina will decrease. This means that the energy-efficiency improvement in primary aluminium production (aluminium smelting) by increased recycling of aluminium equals 1.2% per year in the period 2010-2050.

Alumina production and the associated energy use per region can be seen in Table 2. In 2009, the average energy intensity is estimated at 16.1 GJ/tonne alumina. China, one of the biggest alumina producers, has one of the highest energy intensities. This is due to the fact that China has low quality bauxite reserves (high silica content) that need to be processed in a combination process (Bayer-Sinter). Energy intensities for the combined process range between 24 and 52 GJ/tonne alumina (Li et al., 2008; Liu, 2004). In 2009, the average energy use in alumina refining, excluding China, is estimated at 12.4 GJ/tonne alumina.

Table 10 Alumina production and energy use per region (USGS, 2010a; IAI, 2011; Yanjia and Chandler, 2010; CIEEDAC, 2011)

Region	Alumina production (mtonnes)	Energy Consumption used (GJ/tonne)	Energy consumption (PJ)	Share in energy consumption industry (%)
OECD Europe	5,4	12,3	67	0,6%
OECD Americas	3,5	10,6	37	0,3%
OECD Asia Oceania	20,3	11,3	228	3,5%
Transition Economies	6,3	20,9	132	1,6%
China	23,8	24,5	583	2,0%
India	3,7	14,8	55	1,0%
Rest of developing Asia	0,0	0,0	0	0,0%
Latin America	12,9	9,3	121	2,1%
Africa	0,5	14,8	8	0,2%
Middle East	0,3	24,5	6	0,1%
World	**76,7**	**16,1**	**1236**	**1,3%**
United States	2,4	11,4	27	0,3%

Primary aluminium production and associated electricity consumption per region is given in Table 11.

Table 11 Primary aluminium production and energy use per region in 2009 (USGS, 2010b; IAI, 2011; Yanjia and Chandler, 2010)

Region	Primary aluminium production (mtonnes)	Electrical power used (MWh/tonne)	Electricity consumption (TWh)	Share in electricity consumption industry (%)
OECD Europe	4,1	15,7	64	6%
OECD Americas	4,8	15,3	73	7%
OECD Asia Oceania	2,0	14,4	28	5%
Transition Economies	4,7	15,7	74	14%
China	12,9	14,9	192	9%
India	1,4	14,7	21	6%
Rest of developing Asia	0,3	14,7	4	1%
Latin America	1,9	15,5	30	9%
Africa	2,0	14,7	29	13%
Middle East	2,5	14,7	36	30%
World	**36,9**	**14,9**	**551**	**8%**
United States	1,7	15,3	26	3%
Canada	3,0	15,3	46	29%
Japan	0,0	14,4	0	0%

Additional to the recycling of aluminium, the energy-efficiency can be improved by applying (future) best available technologies. The current worldwide energy intensity for aluminium smelting is 14.9 MWh per tonne of aluminium. The theoretical minimum energy requirement for electrolysis is 6.0 MWh/tonne (IEA, 2009). The current best practice is 13.5 MWh per tonne (IEA, 2009). By 2015 the best practice is estimated by Sinton et al (2002) to be 11

MWh/tonne. Also, the best practice energy use for alumina refining is 9.5-10 GJ/tonne alumina for the Bayer process (ISR, 2000; Worrell et al., 2008) and 25 GJ/tonne alumina for the combined process (Li et al., 2008).

Here we assume that in 2050 the average specific electricity consumption for aluminium smelting can be reduced to 9.5 MWh/tonne in 2050. The average electricity consumption for aluminium production then equals 4.2 MWh/tonne in 2050 (based on 0.7 MWh/tonne for secondary aluminium and 60% recycling). Likewise, we assume that in 2050 the energy use in alumina refining (Bayer process) will be reduced to 6.4 GJ/tonne. Although increased recycling will not affect the energy use per tonne of alumina produced, it will decrease the energy consumption in the alumina producing countries due to the decreased demand of alumina in the world aluminium smelters.

Chemical and petrochemical industry

For the chemical and petrochemical industry we look specifically at the energy-efficiency in steam cracking, ammonia production, methanol production, and chlorine and soda ash production.

Steam Cracking

In the petrochemical industry, oil and gas feedstocks are commonly converted to monomers and building blocks such as ethylene, propylene, aromatics and methanol, with the steam cracking process. These products are further processed into polymers, solvents and resins. Because steam cracking results in a big variety of products in various quantities energy intensities are shown in GJ per tonne of High Value Chemicals (HVC), following the method used by Solomon Associates. Steam cracking accounts for about 20% of the final energy use (excl. feedstocks) in the chemical and petrochemical industry (IEA, 2009). Taking this into account, in 2009 the energy use (excl. feedstocks) for steam cracking is estimated at 4 EJ. Most commonly used feedstocks are naphtha (55%), ethane (30%), liquefied petroleum gas (LPG) (10%) and gas oil (5%) (Ren et al., 2006). The 2005 world average energy intensity (excl. feedstocks and electricity) is estimated by Saygin et al. (2011b) at 16.9 GJ/tonne HVCs[12]. With the implementation of best practice technology (PBT) energy efficiency could improve by 26%, dropping the energy intensity to 12.5 GJ/tonne HVCs, while when best available technology (BAT) is adopted energy efficiency could be further improved by another 15% (Saygin et al. 2011a); an overall energy efficiency improvement of 37%.

Steam cracking can be considered as a combination process consisting of the reaction process where all the different chemicals are produced, and the separation process where the various products are separated. Cryogenic, pressurized product separation is an important energy consuming step. Separation technologies account for 40-45% of the total energy consumption (incl. feedstocks) in the chemical and petrochemical industry (IEA, 2009). The energy use for the separation of aromatics from the pyrolysis gas is not included in the energy intensities appearing above. When included will add another 2 GJ per tonne of extracted product (Saygin et al., 2011a).

[12] In the study from Saygin et al. (2011) chemicals included under HVCs are: ethylene, propylene, benzene, butadiene, acetylene and hydrogen (sold as a fuel). Chemicals not included are: toluene and xylene.

An alternative to cryogenic separation is the separation by membranes. Although membranes are used for a number of products, such as the recovery of hydrogen in refineries, they are not yet used for bulk chemicals. 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). 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. Ion transport membranes can result to 30-40% energy savings when compared to cryogenic separation (IEA, 2009).

Ammonia production consumed more energy than any other process in the chemical industry and accounted for about 18 percent of the energy consumed in this sector. Ammonia is mainly applied as a feedstock for fertilizer production. Current best practice energy-intensity for natural-gas based ammonia production is 10.9 GJ/tonne ammonia (excluding feedstock 20.7 GJ/tonne and electricity 0.3 GJ/tonne). All countries except from China and India use natural gas. In China, most of the ammonia produced is made from coal, and only a small percentage is made from gas, while in India a mix of oil and natural gas is used. The current best practice for oil-based and coal-based ammonia production is estimated at 17.3 and 16.1 GJ/tonne ammonia, respectively (IEA, 2009).

The world average energy use is estimated by Saygin et al. (2011b) at 20.9 GJ/tonne ammonia (excl. feedstock and electricity use). If all countries were to adopt best practice technology energy efficiency would improve by 50%.

Methanol production. Methanol, or else known as methyl alcohol, is the simplest alcohol and it is used as an antifreeze, solvent and fuel. The majority of methanol production (80%) is natural gas-based while the remainder is coal-based mainly taking place in China (IEA, 2007b). The world average energy use in methanol production is estimated at 10.9 GJ/tonne (excl. feedstock and electricity use) (Saygin et al., 2011b). The worldwide adoption of best available technology, 8.8 GJ/tonne (excl. feedstock and electricity), would result in a 20% improvement in energy efficiency.

Chlorine production is the main electricity consuming process in the chemical industry, followed by oxygen and nitrogen production. Chlorine along with sodium hydroxide production is responsible for the 13% of electricity consumption in the chemical and petrochemical industry (Saygin et al., 2011). The most efficient production process for chlorine production is the membrane process which consumes 2600 kWh/tonne chlorine, which is already close to the most efficient technology considered feasible (IEA, 2008 and Sinton et al, 2002). At the moment however, the mercury process is still commonly used for chlorine production, with an energy-intensity of around 4000-4500 kWh/tonne chlorine. Worldwide the average energy-intensity for chlorine production is around 3600[13] KWh/tonne chlorine (IEA, 2008 and Sinton et al, 2002). This corresponds to a savings potential of 28%, based on the application of membrane technology for all chlorine production.

[13] 3000 kWh/tonne in Japan, 3500 kWh/tonne in Western Europe and 4300 kWh/tonne in the United States

Soda Ash is mainly produced for use in the glass industry. Other uses of soda ash are as a water softener, in detergents, in photographic process and in the manufacture of bricks (IEA, 2007b). In the U.S. soda ash is manufactured from natural soda ash deposits and soda recovery from lakes. In the other regions, soda ash is based on synthetic production. In synthetic production, synthetic soda ash is manufactured from limestone and common salt through the ammonia-soda process. The result is light soda which needs to be densified as in the glass industry (main consumer of soda ash) dense soda ash is of preference. Natural production route produces dense soda ash. Energy use in the synthetic route ranges between 10.6 and 13.8 GJ/tonne. Best practice technology (synthetic route) requires 7.5 GJ/tonne of soda ash (IEA, 2007b). The adoption of best practice technology would therefore result in an energy efficiency improvement of about 40%.

For the **average savings potential** in the chemical and petrochemical industry we assume that by 2050 energy-efficiency (only fuel, excluding feedstocks) can be improved by 45%. Also we conservatively assume that by increased recycling and material efficiency specific energy demand can be reduced by another 20%. Together this corresponds to an energy-efficiency improvement of 55%.

When it comes to the electricity consumption in the chemical and petrochemical industry, about 65% of the electricity use is consumed in motor systems (i.e. pumps, fans, compressors), 13% in the production of chlorine and sodium hydroxide, and 22% in other electrolytic and electric arc processes, and non-process related usages (i.e. lighting) (Saygin et al, 2011). Energy efficiency in motor systems can be improved by 40% through the use of highly efficient motors, adjustable speed drives, and advanced process control and optimization while in chlorine production energy efficiency can be improved by 28% via the use of membranes. For the remaining processes that use electricity, we assume that efficiency can be improved by another 40%. Overall, the electricity savings are estimated at about 38%.

Pulp and Paper

The pulp and paper industry (including printing) is the fourth largest industrial energy consumer. In 2009, the pulp and paper industry consumed approximately 6.3 EJ; approximately 7% of the industrial energy use (IEA, 2011b).

The processes responsible for the majority of energy use are chemical pulping, mechanical pulping, paper recycling and paper production. Most of the fuel used is for heat purposes while over a quarter is used for the generation of electricity (IEA, 2009). Main facilities are independent pulp mills and integrated pulp and paper mills. Integrated plants are more efficient as pulp drying can be avoided, however they may have higher fuel and electricity requirements (IEA, 2009).

Wood is the main raw material used in the manufacture of pulp and paper. The pulp and paper industry, unlike other industries, uses large amounts of biomass for energy purposes, covering around half of its energy requirements. The consumption of biomass in the IEA dataset can be under-reported, as in many cases it is included under the non-specified industries (IEA, 2009).

The replacement of old plants with new energy efficient plants will have the greatest potential for energy efficiency improvement. Overgaag et al. (2009) estimated that new plants are 20% more energy efficient than older plants. The employment of new emerging technologies could improve energy efficiency even more in the future. Currently, a number of pulp and paper facilities are close to the end of their operating lifetime and will have to be replaced. Another option for energy efficiency improvements in the short term is retrofitting with more energy efficient equipment. It was estimated by Fraunhofer ISI (2009) that the energy use per tonne of paper can decrease by 7% in 2020.

Some of the most promising energy saving technologies in the pulp and paper industry are gasification, advanced drying technologies and high temperature and high pressure black-liquor recovery boilers (Worrell et al., 2001).

Producing pulp from recovered paper will reduce energy use by 10-13 GJ/tonne, depending on the type of paper and type of pulping substituted (CEPI, 2006; IEA, 2009). In 2010, the world paper recycling rate was 58% (CEPI, 2011). The paper recycling rate is defined as the amount of recovered paper used plus the amount of paper exported to third countries divided by the overall paper consumption. The upper technical limit of recycling rate is estimated at 81% (CEPI, 2006), however the practical limit may be closer to 60% (IEA, 2009). Theoretically, there remains a recycling potential of 23%.

We assume that the energy efficiency from BAT adoption can be improved by 20%. Also, the recycling rate will increase from 58% in 2010 to 81% in 2050. This translates into a 15% further decrease in energy use. Overall the energy efficiency can be improved by 35%.

Other industries

For the energy-efficiency potential of the remaining industries, corresponding to roughly 50% of industrial energy demand, we estimate the decrease in energy intensity by identifying the potential for energy efficiency improvements in cross-cutting measures such as electric motors and pumps.

The energy-efficiency of the other industries can be improved by using state of the art processes, improved material efficiency in product design and material and product recycling. Examples of cross-cutting measures for energy-efficiency improvement are:

- High efficiency motor systems
- Process optimisation and integration
- Improved monitoring and process control

The first two are discussed in more detail as examples below.

Electric 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), which 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), which 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 can 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. (Keulenaar 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. (Keulenaar 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 (Keulenaar et al, 2004). The economic savings potential includes measures with payback times up to three years.

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).

We assume that by implementing cross-cutting measures and by using best practice technology the energy-efficiency can be improved by 50% in 2050. Also we assume that by increased recycling and material efficiency specific energy demand can be reduced by another 30%. Together this corresponds to a savings potential of 65% in 2050.

3.2.1 Energy savings in low energy demand scenarios industry

The overall technical potential is estimated after identifying the most significant (big energy savings) energy-efficiency improvements. In the reference scenario, a part of these energy-efficiency improvements has already been implemented (autonomous and policy induced energy-efficiency improvement). The energy-efficiency improvement occurring in the reference scenario is however unknown (as explained in section 2.1.1), we therefore assume that it is equal to 1% per year for all regions, based on historical developments of energy-efficiency (see e.g. Ecofys (2005), Blok (2005), Odyssee (2005), IEA (2011c)). Therefore, the technical potential in the low energy demand scenarios is the identified technical potential that has not already been implemented in the reference scenario.

Table 12 shows the resulting savings potentials for industry in comparison to the reference scenario per region in 2050. These are based on the technical potentials with the subtraction of the energy-efficiency improvement already included in the reference scenario.

Table 12 Reduction of energy use in comparison to the reference scenario per sector in 2050

	Iron and steel		Aluminium production		Chemical industry		Non-metallic minerals		Pulp and Paper		Other industries	
	Industry - fuels	Industry - electricity	Industry - fuels	Industry - electricity	Industry - fuels	Industry - electricity	Industry - fuels	Industry - electricity	Industry - fuels	Industry - electricity	Industry - fuels	Industry - electricity
OECD Europe	45%	45%	40%	38%	32%	7%	0.6%	0.6%	10%	10%	48%	48%
OECD Americas	64%	64%	40%	38%	32%	7%	0.6%	0.6%	10%	10%	48%	48%
OECD Asia Oceania	51%	51%	40%	39%	32%	7%	0.6%	0.6%	10%	10%	48%	48%
China	69%	69%	40%	38%	32%	7%	0.6%	0.6%	10%	10%	48%	48%
Latin America	79%	79%	40%	38%	32%	7%	0.6%	0.6%	10%	10%	48%	48%
Africa	70%	70%	40%	38%	32%	7%	0.6%	0.6%	10%	10%	48%	48%
Middle East	-52%	-52%	40%	38%	32%	7%	0.6%	0.6%	10%	10%	48%	48%
Transition Economies	79%	79%	40%	38%	32%	7%	0.6%	0.6%	10%	10%	48%	48%
India	63%	63%	40%	38%	32%	7%	0.6%	0.6%	10%	10%	48%	48%
Rest of developing Asia	33%	33%	40%	38%	32%	7%	0.6%	0.6%	10%	10%	48%	48%
World	**66%**	**66%**	**40%**	**38%**	**32%**	**7%**	**0.6%**	**0.6%**	**10%**	**10%**	**48%**	**48%**

For the energy [r]evolution scenarios we assume that a certain share of these potentials are implemented. This share is different per region as shown in Table 13.

Table 13 Share of technical potentials implemented in energy [r]evolution scenario

Industry - fuels	**2009**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
World	80%	80%	80%	80%	80%	80%	80%	80%	80%
OECD Americas	90%	90%	90%	90%	90%	90%	90%	90%	90%
OECD Asia Oceania	90%	90%	90%	90%	90%	90%	90%	90%	90%
OECD Europe	75%	75%	75%	75%	75%	75%	75%	75%	75%
Transition Economies	95%	95%	95%	95%	95%	95%	95%	95%	95%
India	80%	80%	80%	80%	80%	80%	80%	80%	80%
China	90%	90%	90%	90%	90%	90%	90%	90%	90%
Rest of developing Asia	95%	95%	95%	95%	95%	95%	95%	95%	95%
Latin America	90%	90%	90%	90%	90%	90%	90%	90%	90%
Middle East	70%	70%	70%	70%	70%	70%	70%	70%	70%
Africa	70%	70%	70%	70%	70%	70%	70%	70%	70%

Industry - electricity	**2009**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
World	80%	80%	80%	80%	80%	80%	80%	80%	80%
OECD Americas	80%	80%	80%	80%	80%	80%	80%	80%	80%
OECD Asia Oceania	70%	70%	70%	70%	70%	70%	70%	70%	70%
OECD Europe	75%	75%	75%	75%	75%	75%	75%	75%	75%
Transition Economies	80%	80%	80%	80%	80%	80%	80%	80%	80%
India	70%	70%	70%	70%	70%	70%	70%	70%	70%
China	100%	100%	100%	100%	100%	100%	100%	100%	100%
Rest of developing Asia	70%	70%	70%	70%	70%	70%	70%	70%	70%
Latin America	70%	70%	70%	70%	70%	70%	70%	70%	70%
Middle East	80%	80%	80%	80%	80%	80%	80%	80%	80%
Africa	70%	70%	70%	70%	70%	70%	70%	70%	70%

4 Results

This chapter presents the results of this study for buildings and agriculture (4.1) and for industries (4.2).

4.1 Buildings and agriculture

Figure 32 shows the energy demand scenarios for the sector Others on a global level. Energy demand savings represent 36% for electricity use and 28% for fuel use, in comparison to the reference level in 2050. In comparison to 2009, global fuel use in Others decreases slightly from 91 EJ to 86 EJ while electricity use shows a strong increase from 35 EJ to 52 EJ.

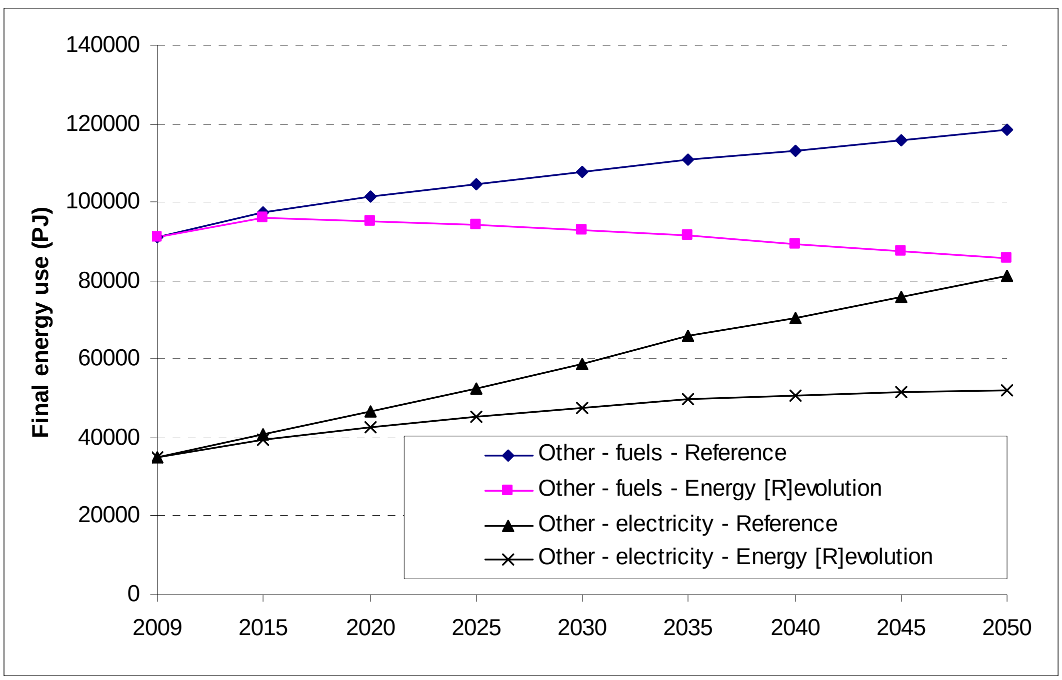

Figure 32 Global final energy use in the period 2009-2050 in Others

Figure 33, Figure 34 and Figure 35 show the final energy demand in the sector Others per region for total energy demand, fuel use and electricity use, respectively.

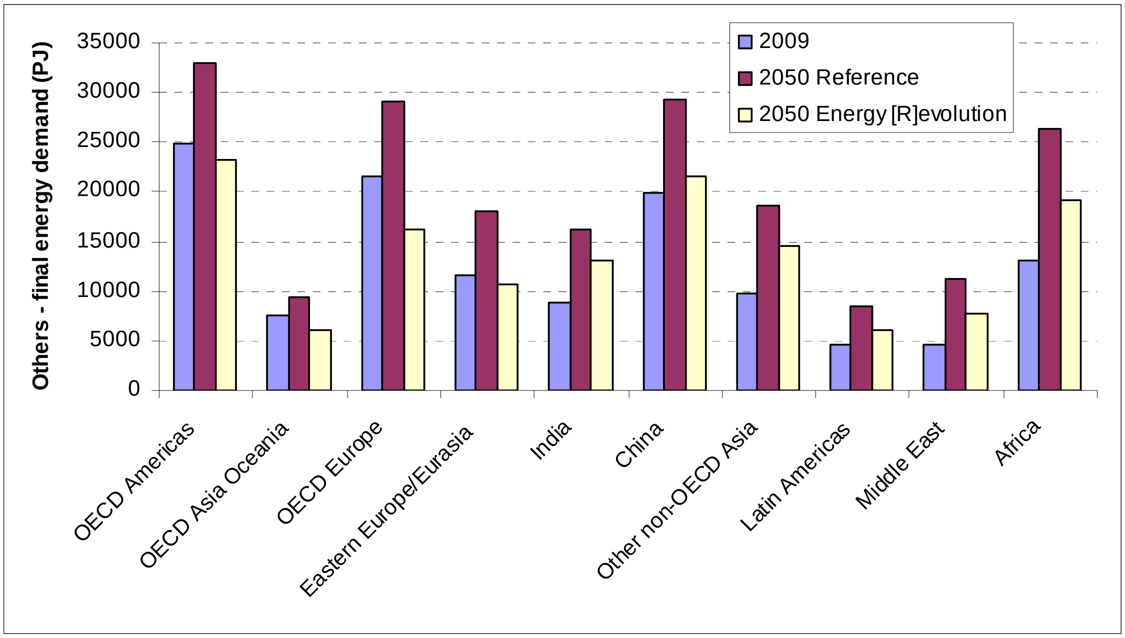

Figure 33 Final energy use in sector Others

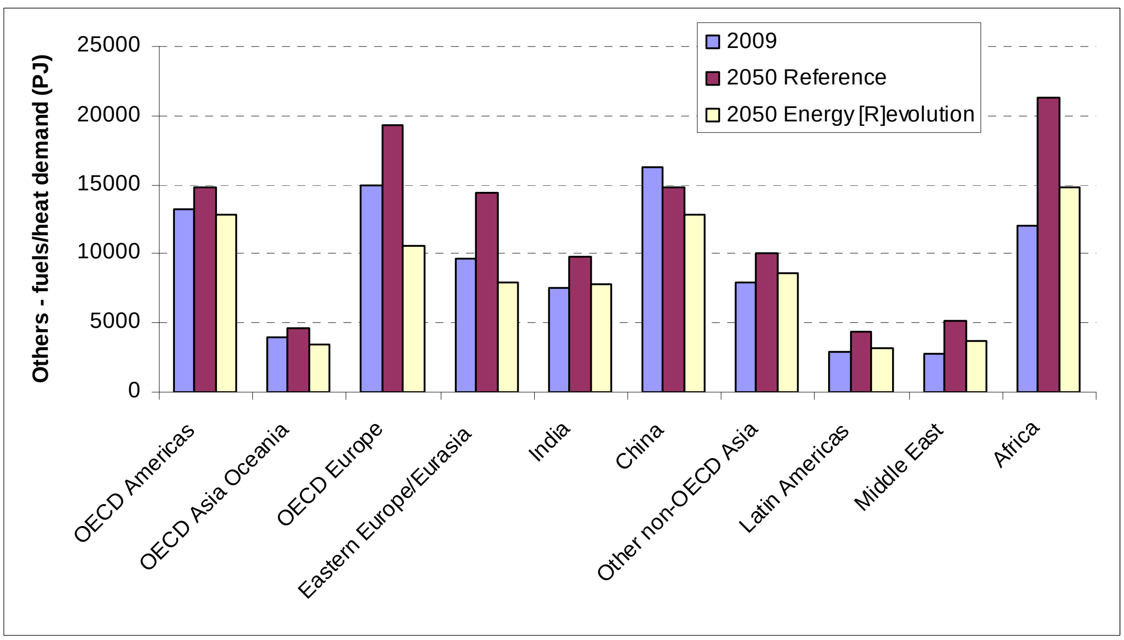

Figure 34 Fuel/heat use in sector Others

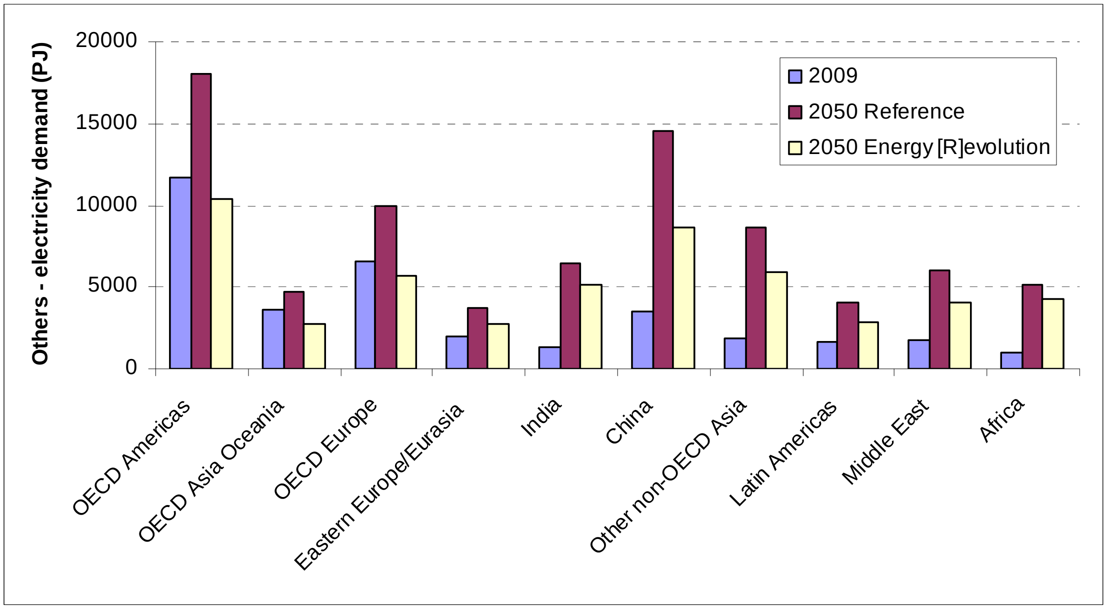

Figure 35 Electricity use in sector Others

4.2 Industry

Figure 32 shows the energy demand scenarios for the sector industry on a global level. Energy demand savings represent 33% for electricity use and 35% for fuel use, in comparison to the reference level in 2050. In comparison to 2009, global fuel use in industry increases slightly from 71 EJ to 72 EJ and electricity use shows a stronger increase from 24 EJ to 43 EJ.

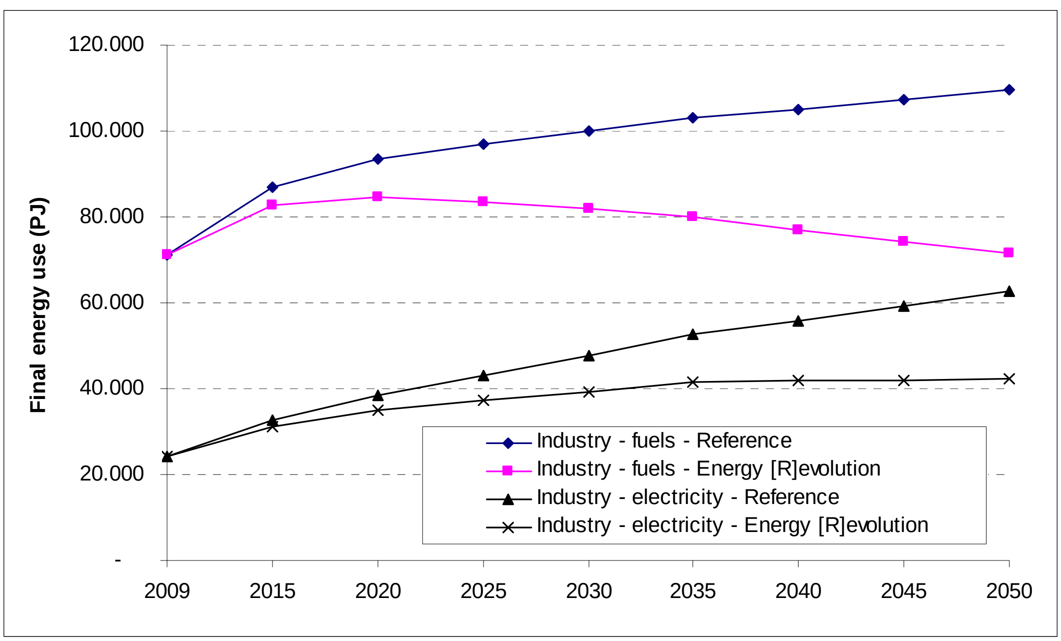

Figure 36 Global final energy use in the period 2009-2050 in industry

Figure 33, Figure 34 and Figure 35 show the final energy demand in the sector industries per region for total energy demand, fuel use and electricity use, respectively

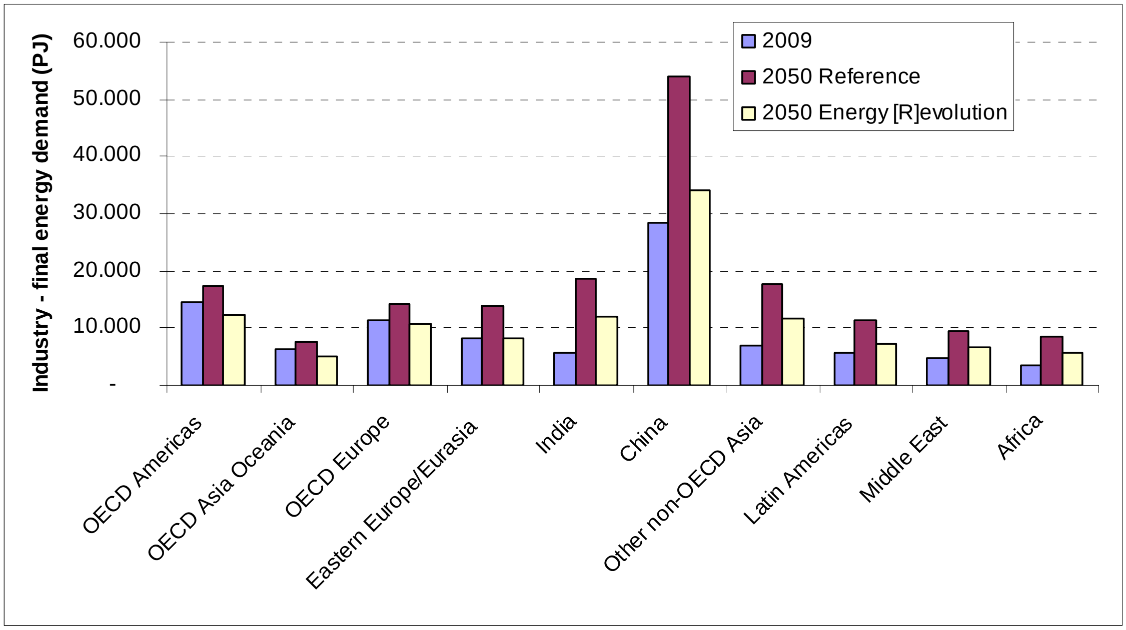

Figure 37 Final energy use in sector industries

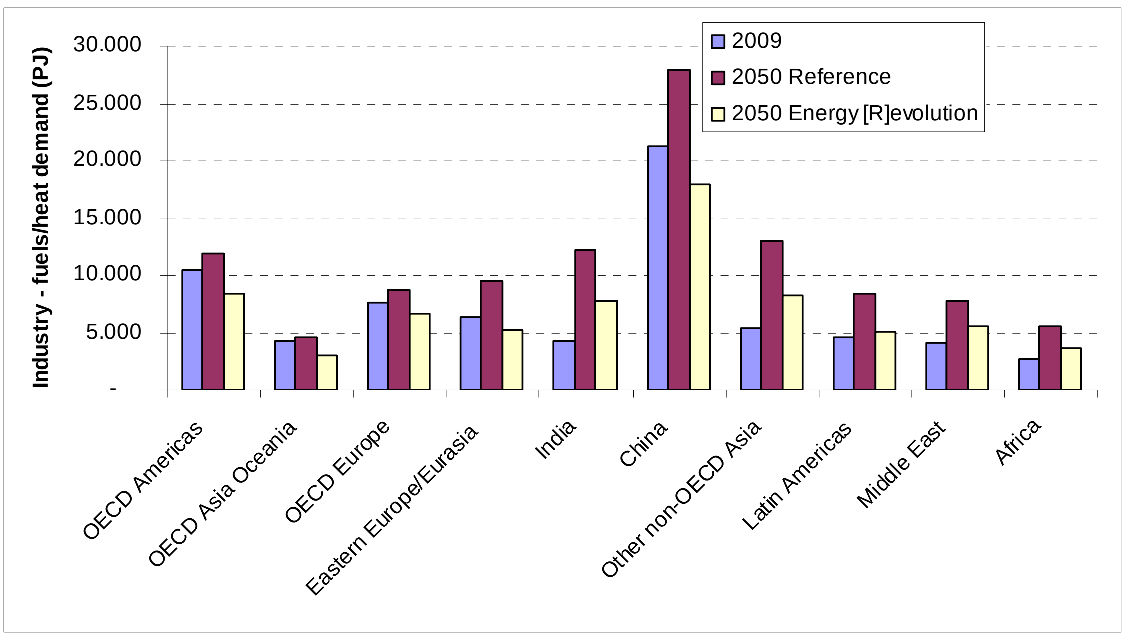

Figure 38 Fuel/heat use in sector industries

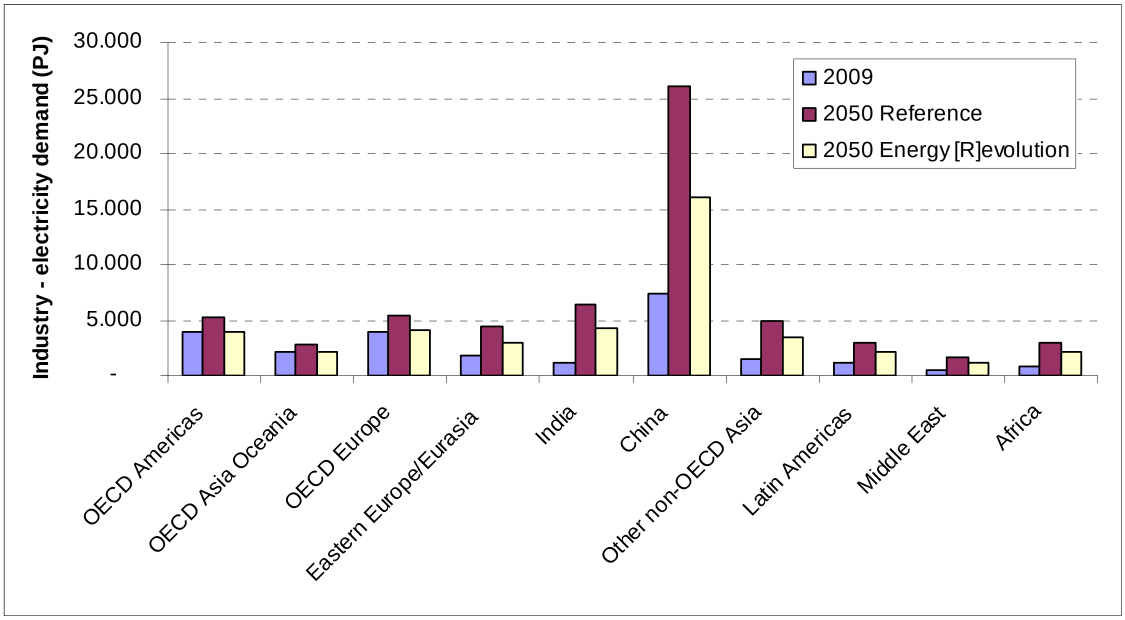

Figure 39 Electricity use in sector industries

5 Policy measures and investments

5.1 Policy measures

Strong energy-efficiency improvement does not tend to happen automatically but typically requires the implementation of effective policy measures. A combination of successful policy measures stimulates energy-efficiency in three ways:

- Set standards for energy-efficiency (5.1.1)
- Address barriers (5.1.2)
- Stimulate innovation (5.1.3)

5.1.1 Set standards

Improving energy efficiency is usually considered as the safest and most cost-effective way to reduce energy use and GHG emissions (IEA, 2009; Worrell et al., 2009). There are plenty of ways to reduce energy use; such as equipment refurbishment or retrofitting, process control improvement, and increase in productivity and recycling rates. Different sorts of standards can help with realising energy-efficiency goals.

Previous chapters have shown that in order to achieve substantial energy savings in the industrial sector, Best Available Technologies (BAT) along with innovative technologies will need to be deployed on a global level. For the realization of such an achievement, major policies will need to be implemented in all the segments of the industrial sector. Governments already use a wide range of policies to enhance industrial energy efficiency; however there still exists considerable room for energy efficiency improvement in all industrial sectors (IEA, 2009). Different sorts of standards can help with realising energy-efficiency goals in industries such as equipment performance standards, international energy management standards and system assessment standards.

Equipment performance standards

Equipment performance standards can have a significant effect on energy consumption (IEA, 2009). Policies will have to be designed in such a way that leaves little room for interpretation from the industry. With the regulation of equipment performance the demand for more energy efficient equipment will increase. An example is the IPPC (2008) (International Pollution Prevention and Control) standard in the EU. To achieve significant energy savings a similar directive could be developed in other regions.

Energy management standards

The development of international energy management standards will have as main goal to provide guidance to industrial facilities on how to integrate energy efficiency into their current management practices. An energy management standard consists of (McKane et al, 2007):

- An action plan that requires accurate and continuous measurement, management, and up-to-date documentation in order to promote continuous energy efficiency improvement;
- a cross-divisional management team;
- policies and actions taken to address all aspects of energy consumption, costs and disposal;
- projects demonstrating the continuous energy efficiency gains;
- all the decisions and actions taken, energy and cost savings, and adopted policies documented in an Energy Manual;
- identification of most important performance indicators;
- regular progress reporting.

Currently, several countries (e.g. Denmark, Ireland, Sweden, and the United States) have national energy management standards in place. All existing and currently being developed energy management standards have certain features in common as they are all compatible with ISO quality management programme (ISO 9000) and environmental management programme (ISO 14000) (McKane et al., 2007). An international approach to energy management standards would have to harmonize all the existing ones.

System assessment standards

System optimization aims to design and operate cross-cutting systems (e.g. compressed air, pumps, and motor systems) that can achieve a reliable production process that uses the least amount of energy in a cost-effective way. The main focus of system optimization is to achieve a balance between energy efficiency improvement and costs. Currently, markets and policy makers focus on the energy performance of individual equipment such as motors, limited to an energy efficiency potential of 2-5% instead of focusing on system optimization. Based on the experience of several programmes in the UK, U.S. and China, the energy efficiency potential in motor systems is about 20% (McKane et al., 2007). The American Society of Mechanical Engineers (ASME) in the U.S. has recently initiated the development of system assessment standards for compressed air, pumping, steam and process heating systems.

Standards for buildings

Energy efficiency improvements in buildings have been subject to policies in most countries for several decades. Examples are the ban of incandescent light bulbs in many countries and the implementation of the One Watt standard for appliances regarding standby power use. For new buildings the standard requirements for insulation have been gradually tightened. Although in many countries the insulation requirements are still behind the state-of-the-art insulation that would be cost-effective (REEEP, 2008). Further measures that are needed for large-scale energy-efficiency improvements in buildings involve (IEA, 2010 and IEA 2011a):

- Tighter building standards and codes for new residential and commercial buildings.
- Large-scale refurbishments of existing buildings, mainly in OECD countries (including improved insulation levels)
- Highly efficient heating, cooling and ventilation systems. Heating systems need to be

both efficient and cost-effective.

  - The deployment of heat pumps for space and water heating predominantly in OECD countries. And the deployment of micro- and mini-CHP for space and water heating, and electricity generation.

- Energy efficiency standards and labelling requirements for all equipment and appliances.

5.1.2 Address barriers

Although the potential for energy-efficiency is large, there are several barriers that inhibit the uptake of energy-efficiency measures, even when they are cost-effective. Energy policies aimed at improving energy-efficiency are often designed to help reduce these barriers. Many studies have demonstrated the existence of market barriers for energy efficiency improvement (IPCC, 2001; DeCanio, 1993; DeCanio, 1994; Sorrell et al., 2004), of which some are market failures. “Market failures” occur when there is a flaw in the way markets operate. Table 14 gives examples of important market failures and market barriers.

Table 14 Market failures and barriers inhibiting energy efficiency improvements (Brown, 2001)

Market barriers and failures
1. Principal agent problem
2. Distortionary fiscal and regulatory policies
3. External costs
4. Insufficient and inaccurate information
5. Low priority of energy issues
6. Capital market barriers

We will discuss these failures and barriers below.

Principal-agent problem

The principal agent problem is a potential barrier to energy policy using economic instruments, as the decision maker may be partially insulated from the price signal given by such policies. In this market failure, the stakeholders have split incentives that may lead to inefficiencies, i.e. the principal (e.g. tenant) has the interest to keep the energy costs of a home or office low as he/she pays the energy bills for the property, while the agent (e.g. the property owner) has a different incentive, i.e. keep investments as low as possible at a given rental income (IEA, 2007b).

The principal-agent problem can be categorized as given in the two-by-two matrix of Table 15, which classifies the technology according to user’s ability to choose the technology and the user’s responsibility for paying associated energy costs.

Table 15 Principal agent classification of energy and end users (Graus and Worrell, 2008)

	Chooses Technology	Does not Choose Technology
Pays Energy Bill	Category 1: No Problem	Category 2: Efficiency Problem

Does not Pay Energy Bill	Category 3: Usage and Efficiency Problem	Category 4: Usage Problem

In category 1, the end user selects the energy-using technology (furnace, car, refrigerator, etc.) and pays for its energy consumption. In this case there is no principal-agent problem because the principal and agent are the same entity.

In category 2, the agent selects the energy-using technology, but the end user (the principal) pays for the energy use. A principal-agent problem exists here, can be called an "efficiency problem". This is the situation in many rented buildings, where the landlord selects the heating system, level of insulation, and other building characteristics but the tenant must pay the heating or cooling bill.

In category 4, the end user neither selects the energy-using technology nor pays the energy bill. We call this a "usage" problem because the end user faces no economic constraint on usage. Here the end users (who are shielded from the price of energy) may consume more energy than is reasonable because they don't pay for it. This is the situation where the landlord selects the level of insulation or the efficiency of the refrigerator and pays the energy bill. This market failure is the reverse of Case 2. Here the landlord is the principal and the tenant is the agent.

In category 3, the end user selects the technology but does not pay the utility bill. For example, in some companies the employees are permitted to select their cars and the companies pay for fuel consumed on both company and private trips. In this case there is a usage and an efficiency problem.

Distortionary fiscal and regulatory policies

Distortionary fiscal and regulatory policies refer to government interventions that inhibit the further use of efficient and clean energy technologies. Examples include:

- Tax policies in many US states that hamper the introduction of energy efficient technologies because e.g. capital costs need to be depreciated over a long period whereas operational cost (including fuel costs) can be fully deducted on an annual basis (IEA, 2007b).
- Various policies that promote purchase of large vehicles in the US: a small business tax deduction for large SUVs; less stringent fuel economy standards for light trucks than for other passenger vehicles, and exemption from the gas-guzzler tax (IEA, 2007b).
- Regulation with respect to access to the electricity grid and administrative procedures, which hamper the further introduction of CHP in various European countries (IEA, 2007b).

Unprized costs (market externalities)

Energy is under prized, because market prices do not take full account of a variety of social costs associated with fuel use. Fossil fuel use produces a variety of unprized costs (or negative externalities) including greenhouse gas emissions; air, water, and land pollution; and fossil fuel supply vulnerabilities associated with the need to import these fuels and the uneven geographic distribution of these resources (IEA, 2007b). These unprized costs result in more fossil energy is being consumed than is socially optimal. Various efforts have been made to quantify the negative externalities. Within the EU funded project ExternE externalities for various energy production technologies have been quantified. Results show that cost for electricity production with coal and lignite in the EU would have to increase by with 3-15 €ct/kWh if negative external impact are taken into account (ExternE, 2003)[14].

Insufficient and inaccurate information

Suboptimal investments in energy efficiency often occur as the result of insufficient and incorrect information. Market efficiency assumes free and perfect information, although in reality information can be expensive and difficult to obtain. Sanstad and Howarth (1994) point out that there is a large body of research documenting that consumers are often poorly informed about technology characteristics and energy efficiency opportunities. Likewise, consumers often lack the ability or time to process and evaluate the information they do have, a situation sometimes referred to as “bounded rationality”

That costs for collecting information can be substantial was shown in a study of 12 Dutch industrial firms. Hein and Blok (1995) found that the cost of collecting information on energy efficiency investments were 2% to 6% of the total cost of the efficiency investment. Similar transaction costs can be expected for the commercial sector, but are likely to be higher (although more difficult to quantify) for residential consumers.

Low energy costs and low price elasticity

Energy efficiency is not a major concern for most consumers because energy costs are not high relative to the cost of many other goods and services. When energy costs are small on an individual basis, it is easy for consumers to ignore them in the face of information gathering and transaction costs.

The relatively low energy costs in comparison to household budgets lead to low price elasticities in the richest countries (IPPC, 2006). The energy price elasticity, refers to the percent change in energy demand associated with each one percent change in price. In general, residential energy price elasticities in OECD countries is typically only -0.2-0.25, meaning that if energy prices increase by 100% energy demand reduces by only 20-25%. If energy expenditures reach a significant proportion of disposable incomes, as in many developing countries and economies in transition, elasticities and the expected impact of taxes and subsidy removal may be higher (IPPC, 2006).

Capital market barriers

Restricted access to capital markets is often considered to be an important barrier to investing in energy efficiency. That is, investments may not be profitable because companies face a high price for capital. Even if organisations have easy access to capital at relatively low prices, the uncertainty associated with the returns from investments may be prohibitive (Schleich and Gruber, 2006).

Residential and small commercial customers face much higher costs of capital than large businesses and utilities. Beyond the higher cost of capital, many energy efficiency projects do not qualify for traditional sources of financing or may not qualify under conventional lending criteria (IEA, 2007b).

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[14] ExternE (2003) External Costs. Research results on socio-environmental. damages due to electricity and transport. EUROPEAN COMMISSION. Directorate-General for Research Directorate J-Energy. Brussels

Specific barriers for energy-efficiency improvement in industries

Many studies show negative costs for most energy efficiency measures in industry, meaning that the payback time of measures is below their lifetime. It should be noted though that although most measures payback within their lifetime it does not mean that they are necessarily profitable from a company's perspective. Investment criteria in terms of desired payback times, restrictions to the height of up-front capital costs and opportunity costs in the end, determine the attractiveness of measures. Furthermore companies can be hesitant to implement measures that might (temporarily) reduce plant reliability. The most important barriers that can furthermore prevent energy efficiency and emission reduction measures from being implemented and that inhibit investment in technologies that are both energy efficient and economically efficient include:

- The fact that capital goods have not yet been fully depreciated;
- The lack of access to capital for investments in energy efficiency measures and emission reduction measures;
- The fact that investments in other projects within the company are considered more important or more efficient.

Literature provides ample empirical evidence for the existence of such barriers in the industry sector.

Effective policies to tackle barriers

Industries

Barriers to energy efficiency mean that industries cannot reach their energy efficiency potential, and reduce production costs. To overcome these issues, governments implement a wide variety of policies. Main approaches to address these issues are to (IEA, 2009):

- Create technology specifications and incentives in cross-cutting equipment (e.g. motors, boilers, pumps);
- Introduce performance incentives, targets and agreements at a plant or sectoral level, without specifying technologies and processes, encouraging in this way the industry firms to identify and assess the various ways that could achieve the targets;
- Determine management specifications and incentives that will stimulate firms to identify and carry out specific technical actions;
- Provide industrial firms with all the required information and tools for identifying and assessing all available technical options.

Which policy will most effectively address a specific barrier will need to be thoroughly assessed in each case. Individual barriers will need to be dealt in different ways depending on the situation. Several policy measures have been evaluated analyzing among others whether and to what extent they can reduce energy use, GHG emissions and stimulate innovation (IEA, 2009). Administrative policies such as the regulation of equipment performance, process efficiency and process configuration, the regulation for energy management and the negotiated commitments/agreements can play a key role in decreasing the industrial energy use. Voluntary agreements along with an implicit threat of future taxes or regulations, or voluntary agreements in combination with energy or carbon taxes have shown to be the most efficient agreements in improving energy efficiency in the industrial sector (Worrell et al, 2009). Such voluntary agreements can provide energy savings beyond business-as-usual levels (Bjørner and Jensen, 2002), while being cost-effective (Worrell et al., 2009). Economic policies, such as the implementation of taxes and cap and trade schemes could also offer substantial energy savings. On the other hand financial incentives and tax reductions have shown to have only a medium potential on energy efficiency improvement (IEA, 2009).

Recycling of materials, such as steel, aluminium, plastic and wood, can achieve substantial energy savings, reduce GHG emissions, and decrease waste disposal and resource exploitation. Recycling rates vary strongly by country. Sharing the best policy practice on recycling and efficient material use between several countries could therefore play a key role in energy savings.

Buildings

To tap into the potential energy-efficiency improvement, policies are required that provide an incentive at all stages in the supply chain to bring technologies to the market. A broad range of policy measures is available, including regulatory and voluntary approaches, financial incentives, fiscal measures and procurement policies. Many have been tried successfully by in countries and need to be replicated in more countries and regions (IEA, 2010). Furthermore they need to be applied to a wider range of appliances, including ICT and home entertainment. E.g. policies are needed to ensure that manufacturers design all their devices with the ability to move automatically to the lowest power needed for their required functionality (IEA, 2010). This will minimise the time that appliances that no one is using continue to consume unnecessary power.

Furthermore, energy labels have become widespread for major appliances. But there is very little available public information on the running costs and savings potential of smaller appliances. For example, consumers are largely unaware of the consumption of current TV technologies, and there is little market incentive for the commercialisation of televisions with back-light modulation or organic light-emitting diodes technologies that could reduce consumption by approximately 50% (IEA, 2010). An effective labelling system could help to inform consumers and create a market pull for efficient technologies. For example in Europe, the intention to make labelling mandatory for televisions, already resulted in more efficient products entering the market (IEA, 2010).

5.1.3 Stimulate Innovation

New technologies which are still on initial stages of their development will have to be supported during their research, development and demonstration (RD&D) stages. Therefore, more government support on investments on RD&D in promising technologies, such as, separation membranes for the chemical and petrochemical industry, black liquor and biomass gasification for the pulp and paper industry and inert anodes for the primary aluminium industry could significantly contribute to the decrease of the future energy use. Investment will also be needed in the research of new technologies that have not yet been identified and which could reduce future energy use.

When looking at a strong increase of energy-efficiency improvement in a period of 35-40 years, it is important to encourage innovation in the field of energy-efficient technologies e.g. by subsidizing R&D. Other important options for encouraging innovation are (Blok, 2005b):

- Technology development covenants can be used in which the government and companies reach an agreement to work together to achieve a concrete technological goal.
- Technology-forcing standards can be implemented in which governments stipulates a standard that will only come into force after some time (such as a decade). Generally, the industry concerned will not currently be able to comply with the standard, so it will be forced to develop new technology. One example of a technology-forcing standard is the Californian requirement that zero-emission vehicles should take a certain market share in the future.
- Another option is technology procurement, where a large buyer of equipment (or a group of buyers) sets ambitious standards regarding the energy efficiency of the equipment it proposes to buy. If the buyer or buyers purchase a sufficiently large share of the production of a particular product, the suppliers will be motivated to develop or market the efficient equipment. A technology procurement approach in Sweden was successful in increasing the energy efficiency of heat pumps by 30% while lowering their cost by 30%.
- Market transformation policies, consisting of a tailored mix of subsidies for the introduction of new energy-efficient technologies, demonstration projects, procurement and standards.
    - Market introduction subsidies. Although subsidies have their disadvantages (free-rider effects, relatively high costs to the government), they can be effective, especially in the early stages of market introduction of energy-efficient technologies.
- Demonstration project schemes. In the case of large-scale industrial equipment, the last step in scaling up to a commercial or near-commercial scale is relatively expensive and it entails considerable risks. New technologies often strand at just this point. Therefore it is still necessary and useful for governments to support demonstration projects.

5.2 Investments

Based on UBA (2009) average investment costs for energy-efficiency measures in transport, buildings and industry are calculated. These investment costs are based on the data in **Table** 19 in the appendix. The calculations take into account a discount rate of 6%.

Together with the savings potentials in the different sectors in comparison to the reference scenario the investment costs needed for the energy-efficiency measures in the energy [r]evolution scenario are calculated as shown in Table 16. Note that the uncertainties in these values are very high.

Table 16 Incremental investment costs in Energy [R]evolution scenario for energy-efficiency measures

	Average investment costs (€/GJ final)	Annual investment costs in 2030 (trillion EUR/yr)	Annual investment costs in 2050 (trillion EUR/yr)	Cumulative investment costs 2015-2050 (trillion EUR)	Average annual investment costs period 2015-2050 (trillion EUR/yr)
Transport	30	0.5	1.4	20.1	0.6
Industry	3	0.1	0.2	2.8	0.1
Buildings	22	0.6	1.4	19.2	0.5
Total		**1.3**	**2.9**	**42.0**	**1.2**

As a comparison, global GDP in 2050 equals 245.5 trillion US$_2011 in the energy [r]evolution scenario, so about 1% of GDP needs to be spent on energy efficiency investment costs, annually in 2050. Total investment costs (cumulative for the period 2015-2050) amount to 42 trillion EUR. If we divide this over period 2015-2050 we get annual investment costs of 1.2 trillion EUR/yr over the period 2015-2050. In comparison to 71 trillion US$2011 GDP globally in 2009 this corresponds to about 1.5% of GDP in 2009 per year to achieve energy [r]evolution scenarios in terms of energy demand. Note that these costs do not take into account the benefits from energy savings options.

The calculated costs for the buildings sector may be high. The BLUE map scenario, which has about the same energy savings than the energy [r]evolution scenario for buildings, has lower estimates for needed investment costs (IEA, 2010). Investments in the BLUE MAP scenario for buildings amount to 12.3 Trillion USD, in comparison to 19 Trillion EUR in our calculation (see Figure 40).

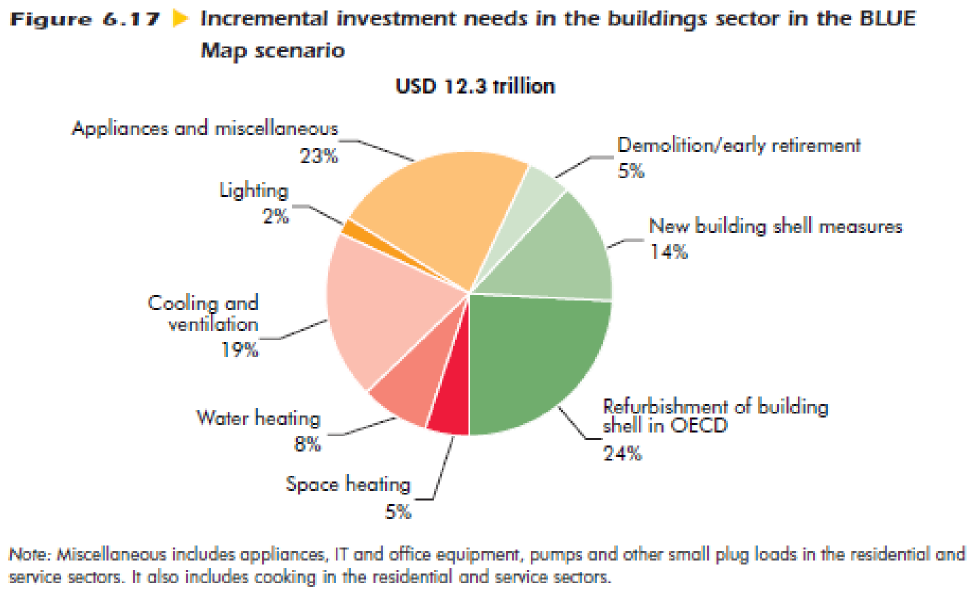

Figure 40 Incremental investment costs in buildings in the BLUE Map scenario (IEA, 2010)

For industry the BLUE Map scenario costs are more in the same line as our costs. IEA BLUE Map needs 2-2.5 trillion USD incremental investment costs for industries, in comparison to 2.8 trillion EUR in our calculations.

Also for transport investment costs are in the same order of magnitude. Total additional investment costs for vehicles in the BLUE Map scenario to 2050, relative to the Baseline, amount to about USD 22 trillion.

Total investments in the BLUE Map scenario in addition to baseline are 46 trillion USD (of which 9.5 trillion for the power sector), which are 17% more than in the baseline; 270 trillion. Cumulative fuel savings amount to 112 trillion USD in comparison to baseline. Using a discount rate of 10%, this means that net savings in the BLUE Map scenario amount to 8 trillion USD (IEA, 2010).

References

- ACEEE (American Council for an Energy-Efficient Economy). (2007). Consumer Guide to Home Energy Savings - Cooling Equipment. http://www.aceee.org/consumerguide/cooling.htm#reduce
- Austrian Energy Agency (2006). Keep Cool – Local and Individual Adaptation. http://www.energyagency.at/publ/pdf/keepcool_adaptation.pdf
- Bertoldi, P. and B. Atanasiu. (2006). Electricity Consumption and Efficiency Trends in the Enlarged European Union – Status Report 2006. Institute for Environment and Sustainability.
- Bianchini, R. and R. Rajamony (2004). Power and Energy Management for Server Systems. *Computer* **37**, pp. 68-74
- Bettgenhäuser, K., T. Boermans and S. Schimschar (2009). Sectoral Emission Reduction Potentials and Economic Costs for Climate Change (SERPEC-CC). Residential buildings and service sector. Ecofys, Netherlands.
- Bjørner, T. B., and Jensen, H. H. (2002). "Energy taxes, voluntary agreements and investment subsidies - A micro panel analysis of the effect on Danish industrial companies' energy demand." Resource and Energy Economics, 24, 229–249.
- 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.
- Blok, K. (2005b). Policies for tapping the energy efficiency potential – a review. Ecofys, Utrecht, the Netherlands.
- Bootstrike, 2008, LCD vs CRT Pros and Cons (A Quick Overview), http://bootstrike.com/Articles/LCDvsCRT/
- Bray, M. (2006). Review of Computer Energy Consumption and Potential Savings. White paper. Dragon Systems Software Limited (DssW). http://www.dssw.co.uk/research/computer_energy_consumption.pdf
- Brown (2001). Market failures and barriers as a basis for clean energy policies. Energy Policy 29 (2001) 1197–1207
- Canadian Industrial Energy End-Use and Data Analysis Centre (CIEEDAC). 2009.
- Confederation of European Paper Industries (CEPI). 2006. "Europe Global Champion in Paper Recycling: Paper Industries Meet Ambitious Target" Press Release, July, Brussels.
- Confederation of European Paper Industries (CEPI). 2011. "CEPI Sustainability Report 2011". November, Brussels.
- CNET (2012). CNET Energy Efficiency Guide. HDTV power consumption compared. http://reviews.cnet.com/green-tech/tv-consumption-chart/
- Darling, D. (2005) Solar Cooling. The Encyclopedia of Alternative Energy and Sustainable Living. http://www.daviddarling.info/encyclopedia/S/AE_solar_cooling.html
- DeCanio, S. (1993). Barriers within Firms to Energy-Efficiency Investments. Energy Policy 21: 906-914.
- DeCanio, S. (1994). Agency and Control Problems in US Corporations: the Case of Energy-Efficient Investment Projects. Journal of Economics of Business 1: 105-122.

- Ecofys (2005). Kosteneffectieve energiebesparing en klimaatbescherming. De mogelijkheden van isolatie en de kansen voor Nederland. Utrecht. http://www.ecofys.nl/nl/publicaties/documents/Kosteneffectieve_energiebesparing_en_klimaatbeschermingSep2005.pdf
- Energy Star. (2008). Compact Fluorescent Light Bulbs. http://www.energystar.gov/index.cfm?c=cfls.pr_cfls
- Enviroharvest (2008). Heat recovery. http://www.enviroharvest.ca/heat_recovery.htm
- Evening Breeze (2008). www.eveningbreeze.com
- Fan, X., W.-D. Weber, L. Barroso. (2007). Power Provisioning for a Warehouse-sized Computer. Proceedings of the ACM International Symposium on Computer Architecture, San Diego, CA, June 2007. http://labs.google.com/papers/power_provisioning.pdf.
- Fichter, K. (2007) Energiebedarf von Rechenzentren Trends, Effizienzpotenziale, Zukunftsmärkte. BITKOM Anwenderforum „IT-Infrastruktur & Energieeffizienz“. www.borderstep.de
- Fruehan, R.J., O. Fortini, H.W. Paxton and R, Brindle (2000). Theoretical minimum energies to produce steel for selected conditions. Carnegie Mellon University, Pittsburgh. United States.
- Global Aluminium Recycling Committee, (GARC). 2009. “Global Aluminium Recycling: A Cornerstone of Sustainable Development”. http://www.world-aluminium.org/cache/fl0000181.pdf.
- Graus, W. and E. Worrell (2006). Leased cars in the Netherlands. Energy use affected by principal agent problem. Ecofys, Utrecht, the Netherlands.
- Graus, W. and E. Worrell (2008). “The Principal-Agent Problem and Transport Energy Use: Case Study of Company Lease Cars in the Netherlands.” *Energy Policy* (10), pp. 3745-3753.
- Graus, W.H.J., Blomen, E. & Worrell, E. (2011). Global energy efficiency improvement in the long term: a demand- and supply-side perspective. Energy efficiency, 4(3), 435-463.
- Harmelink, M. and K. Blok (2004). Elektriciteitsbesparing als alternatief voor de bouw van nieuwe centrales. Ecofys, Utrecht, the Netherlands.
- Hein and Blok (1995) Hein, L.G. and K. Blok. 1995. “Transaction Costs of Energy Efficiency Improvement.” In Proceedings of the 1995 ECEEE Summer Study. 1 (2): 107.
- Hendel-Blackford, S., T. Angelini, S. Ozawa. (2007). Energy efficiency in life-styles: Europe and Japan. Ecofys for EU-Japan Centre for Industrial Cooperation.
- Horowitz, N. (2007). NRDC Study of Set Top Box and Game Console Power Use. http://www.energystar.gov/ia/partners/prod_development/revisions/downloads/settop_boxes/NRDC_SetTopBox_Data_IEA.pdf
- International Aluminium Institute (IAI). 2011. IAI Statistics: http://www.world-aluminium.org/Statistics
- IEA (2003). Cool Appliances - Policy Strategies for Energy Efficient Homes. https://www.iea.org/textbase/nppdf/free/2000/cool_appliance2003.pdf
- IEA (2006). Light’s Labour’s Lost: Policies for Energy-Efficiency Lighting.
- IEA (2006b). Energy Technology Perspectives – Scenarios and strategies to 2050. OECD/IEA, 2006.
- IEA (2007). Energy use in the New Millennium – Trends in IEA Countries. OECD/International Energy Agency.
- International Energy Agency (IEA). 2007b. Tracking Industrial Energy Efficiency and CO_2 Emissions. Paris, France: OECD/IEA; 2007.
- IEA (2008). Indicators for industrial energy-efficiency and CO_2 emissions. A technology perspective. . International Energy Agency, Paris, 2008.

- IEA (2009). Energy Technology Transitions for Industry: Strategies for the Next Industrial Revolution. Paris, France: OECD/IEA, 2009.
- IEA (2009b). Gadgets and Gigawatts. International Energy Agency. Paris, France.
- IEA (2010). Energy Technology Perspectives 2010 – Scenarios and Strategies to 2050. International Energy Agency. Paris, France.
- IEA (2011a). World Energy Outlook 2011 edition. International Energy Agency. Paris, France.
- IEA (2011b). Energy Balances 2011 edition with 2009 data. International Energy Agency. Paris, France.
- IEA (2011c). IEA Scoreboard 2011. 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.
- IISI (2011). IISI statistical yearbook 2011. http://www.worldsteel.org/statistics/statistics-archive/yearbook-archive.html
- IPCC (2001) IPCC, Climate Change 2001: Mitigation. A Report of Working Group III of the Intergovernmental Panel on Climate Change, IPCC Working Group III, 2001.
- IPCC (2007). Special Report on Emission Scenarios. A Special Report of Working Group IV of the Intergovernmental Panel on Climate Change. Cambridge University Press, 2007
- IPCC (2007a). Fourth assessment report. Working Group III: Mitigation of Climate Change. Cambridge University Press. http://www.ipcc.ch/publications_and_data/ar4/wg3/en/ch6s6-4-4-2.html
- International Pollution Prevention and Control (IPPC). 2008. Directive 2008/1/EC of the European Parliament and of the Council of 15 January 2008 concerning Integrated Pollution Prevention and Control. http://ec.europa.eu/environment/air/pollutants/stationary/ippc/summary.htm
- JRC (2008). EU Code of Conduct for Data Centres.
- Keulenaar et al. (2004). Energy efficiency motor systems. European Copper Institute.
- Kim Y. and Worrell E (2002). "International Comparison of CO2 Emission Trends in the Iron and Steel Industry." *Energy Policy* (30), pp 827-838.
- Koomey, J. (2007). Estimating Total Power Consumption by Servers in the U.S. and the World. Lawrence Berkeley National Laboratory. http://hightech.lbl.gov/documents/DATA_CENTERS/svrpwrusecompletefinal.pdf
- Kumana, J. (2000). The Pinch Analysis. http://www.oilandgasnewsworldwide.com/bkArticlesF.asp?Article=17610&Section=2463&IssueID=382
- 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
- Li, W., J. Liu, Z. Liu, Y. W. 2008. "The Most Important Development Issues of Chinese Alumina Industry". *Light Metals*, pp. 191-195.
- Liu, L., L. Aye, Z. Lu, P. Zhang. 2006. "Analysis of the Overall Energy Intensity of Alumina Refinery Process Using Unit Process Energy Intensity and Product Ratio Method." *Energy*, 31, 1167-1176.
- McKane, A., R. Williams, W. Perry, T. Li. 2007. "Setting the Standard for Industrial Energy Efficiency." Industrial Management Issues, Topic 9, Paper 070.
- Neelis, M. and M. Patel (2006). Long-term production, energy consumption and CO_2 emission scenarios for the worldwide iron and steel industry. Utrecht University.
- Overgaag, M., R. Harmsen and A. Schmitz (2009). SERPEC-CC Industry & refinery sector.

Ecofys, 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. K. Blok and E. Worrell (1998). "Benchmarking the energy efficiency of the Dutch energy-intensive industry", A preliminary assessment of the effect on energy consumption and CO2 emissions, Depart-ment of Science, Technology and Society, Utrecht University. Utrecht, The Netherlands.
- REEEP (2008). Global energy-efficiency status report. Ecofys, Netherlands.
- REEEP (2009). Implementation of a Dissemination Strategy for Efficient Cook Stoves in Northeast Brazil.
- Ren, T., M. Patel, and K. Blok. 2006. "Olefins From Conventional and Heavy feedstocks: Energy Use in Steam Cracking and Alternative Processes." *Energy* (31), pp. 425-451.
- Roth, K. W., Goldstein, F. and Kleinman, J. (2002), 'Energy Consumption by Office and Telecommunications Equipment in Commercial Buildings: Volume I', Arthur D. Little, Inc. (reference: 72895-00), Report for Office of Building Equipment, Massachusetts
- Sanstad, A.H. and R.B. Howarth. 1994. "Normal markets, market imperfections, and energy efficiency." Energy Policy 22(10): 811-818.
- Saygin, D., E. Worrell, M.K. Patel, D. J. Gielen. 2011a. "Benchmarking the Energy use of Energy-Intensive Industries in Industrialized and in Developing Countries," *Energy* 36 (2011), pp. 6661-6673.
- Saygin, D., M. K. Patel, E. Worrell, C. Tam, D. J. Gielen. 2011b. "Potential of Best Practice Technology to Improve Energy Efficiency in the Global Chemical and Petrochemical Sector," *Energy* 36 (2011), pp. 5779-5790.
- 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.
- Schleich J. and E. Gruber (2006). Beyond case studies: Barriers to energy efficiency in commerce and the services sector. Energy Economics (2006)
- Sorrel, S., E. O'Malley, J. Schleich and S. Scott Eds. 2004. The Economics of Energy Efficiency. Edward Elgar, Cheltenham, UK.
- UBA (2009). Role and potential of renewable energy and energy-efficiency for Global Energy Supply. DLR/Ecofys/Wuppertal Institute.
- United Nations (2011). UNEP World Population Prospect (2010 revision), medium variant.
- United States Geological Survey (USGS). 2010a. 2010 Minerals Yearbook – Bauxite and Alumina [Advance Release].
- United States Geological Survey (USGS). 2010b. 2010 Minerals Yearbook – Aluminum [Advance Release].
- US DOE EERE (United States Department of Energy; Energy Efficiency and Renewable Energy) (2008) Inventions & Innovation Project Fact Sheet. High Energy Efficiency Air Conditioning. http://www1.eere.energy.gov/inventions/pdfs/nimitz.pdf
- US EPA (United States Environmental Protection Agency) (2007). Cool Roofs. http://www.epa.gov/heatisld/strategies/coolroofs.html
- US EPA (United States Environmental Protection Agency) (2007a). Report to Congress on Server and Data Center Energy Efficiency - Public Law 109-431. http://www.energystar.gov/ia/partners/prod_development/downloads/EPA_Datacenter_Report_Congress_Final1.pdf

- US EPA (United States Environmental Protection Agency) (2006). 6. Lighting. http://www.energystar.gov/ia/business/EPA_BUM_CH6_Lighting.pdf?8c33-87fe
- UU (2001). Icarus-4. Universiteit Utrecht. The Netherlands.
- WBCSD (World Business Council on Sustainable Development) (2005). Pathways to 2050 – Energy and Climate Change.
- Webber, C., J. Roberson, M. McWhinney, R. Brown, M. Pinckard, J. Busch. (2006) After-hours power status of office equipment in the USA. *Energy* 31, pp. 2823–2838.
- Wesselink, B, R. Harmsen, W. Eichhammer (2010) Energy Savings 2020, How to triple the impact of energy saving policies in Europe, Ecofys, Fraunhofer ISI for the European Climate Foundation.
- World Business Council for Sustainable Development/Cement Sustainability Initiative (WBCSD/CSI 2009). Global Cement Database on CO_2 and Energy. http://www.wbcsdcement.org/index.php?option=com_content&task=view&id=57&Itemid=118
- Worrell, E., N. Martin, N. Angolan, D. Einstein, M. Krushchev, and L. Price. 2001. Opportunities to Improve Energy Efficiency in the Pulp and Paper Industry. Lawrence Berkeley National Laboratory. Berkeley, CA. LBNL-48353.
- Worrell, E., L. Price, M. Neelis, C. Galitsky, Z. Nan. 2008. World Best Practice Energy Intensity Values for Selected Industrial Sectors. Lawrence Berkeley National Laboratory. Berkeley, CA. LBNL-62806.
- Worrell, E., L. Bernstein, J. Roy, L. Price, J. Harnisch. 2009. “Industrial Energy Efficiency and Climate Change Mitigation.” Energy Efficiency, 2, 109-123.
- Yanjia, W., and Chandler W. 2010. “The Chinese Non-Ferrous Metals industry – Energy Use and CO_2 Emissions.” *Energy Policy*, 38, 6475-6484.

Appendix

Reference scenario

Final energy consumption (PJ)		2009	2015	2020	2025	2030	2035	2040	2045	2050
Industry - fuels	World	71134	86925	93509	96780	100078	103132	105065	107267	109580
Industry - fuels	OECD Americas	10475	12013	12103	12036	11969	11842	11784	11842	11960
Industry - fuels	OECD Asia Oceania	4308	4769	4878	4890	4902	4884	4812	4741	4670
Industry - fuels	OECD Europe	7548	8820	8888	8874	8860	8826	8653	8620	8728
Industry - fuels	Eastern Europe/Eurasia	6290	6877	7382	7735	8088	8515	8858	9214	9585
Industry - fuels	India	4354	5875	6934	7846	8758	9712	10484	11317	12190
Industry - fuels	China	21223	27525	29785	29783	29782	29482	29001	28528	27858
Industry - fuels	Other non-OECD Asia	5454	7190	8459	9388	10316	11273	11898	12433	12944
Industry - fuels	Latin Americas	4612	5713	6209	6650	7090	7532	7834	8108	8391
Industry - fuels	Middle East	4176	4992	5539	5939	6338	6728	7052	7391	7746
Industry - fuels	Africa	2695	3151	3333	3639	3973	4338	4692	5074	5508

Final energy consumption (PJ)		2009	2015	2020	2025	2030	2035	2040	2045	2050
Industry - electricity	World	24265	32716	38510	42994	47514	52514	55827	59336	62866
Industry - electricity	OECD Americas	3972	4750	4947	5027	5107	5130	5181	5233	5285
Industry - electricity	OECD Asia Oceania	2077	2524	2683	2757	2830	2879	2865	2850	2836
Industry - electricity	OECD Europe	3974	4638	4842	4989	5137	5249	5302	5354	5408
Industry - electricity	Eastern Europe/Eurasia	1860	2324	2640	2910	3181	3488	3765	4065	4388
Industry - electricity	India	1175	1776	2352	2964	3575	4325	4933	5627	6425
Industry - electricity	China	7341	11789	15251	17627	20004	22651	23904	25103	26041
Industry - electricity	Other non-OECD Asia	1395	1869	2278	2669	3061	3523	3929	4383	4870
Industry - electricity	Latin Americas	1210	1508	1716	1911	2105	2308	2523	2757	3013
Industry - electricity	Middle East	437	562	681	816	951	1111	1260	1430	1622
Industry - electricity	Africa	823	975	1119	1323	1564	1849	2165	2535	2979

Final energy consumption (PJ)		2009	2015	2020	2025	2030	2035	2040	2045	2050
Other - fuels	World	91303	97526	101280	104396	107600	110929	113209	115679	118544
Other - fuels	OECD Americas	13163	13173	13303	13483	13663	14018	14299	14585	14877
Other - fuels	OECD Asia Ocear	3925	4235	4352	4453	4555	4677	4654	4631	4608
Other - fuels	OECD Europe	14942	15957	16698	17299	17899	18556	18786	19018	19254
Other - fuels	Eastern Europe/Eu	9654	10353	11060	11662	12263	12955	13409	13879	14366
Other - fuels	India	7598	8135	8539	8785	9032	9243	9410	9581	9766
Other - fuels	China	16256	17656	17637	17154	16670	16006	15477	15071	14869
Other - fuels	Other non-OECD A	8001	8559	8999	9315	9631	9843	9956	10004	10015
Other - fuels	Latin Americas	2940	3268	3445	3616	3786	3947	4065	4187	4312
Other - fuels	Middle East	2821	3190	3492	3770	4048	4343	4599	4871	5158
Other - fuels	Africa	12004	13000	13754	14859	16052	17340	18554	19852	21321

Final energy consumption (PJ)		2009	2015	2020	2025	2030	2035	2040	2045	2050
Other - electricity	World	34933	40631	46714	52701	58765	65793	70581	75731	81192
Other - electricity	OECD Americas	11733	12543	13459	14402	15345	16283	16858	17453	18069
Other - electricity	OECD Asia Ocear	3571	3874	4092	4281	4470	4674	4697	4721	4744
Other - electricity	OECD Europe	6603	7046	7607	8185	8764	9343	9530	9721	9916
Other - electricity	Eastern Europe/Eu	1923	2052	2327	2569	2811	3071	3286	3516	3762
Other - electricity	India	1309	1805	2331	2970	3610	4485	5050	5688	6412
Other - electricity	China	3547	5636	7649	9131	10612	12250	13120	13914	14505
Other - electricity	Other non-OECD A	1819	2306	2890	3680	4470	5568	6469	7466	8584
Other - electricity	Latin Americas	1686	1930	2184	2465	2746	3089	3391	3722	4085
Other - electricity	Middle East	1720	2190	2617	3113	3609	4188	4722	5326	6006
Other - electricity	Africa	1022	1250	1559	1905	2327	2843	3458	4205	5108

Low energy demand scenario

Final energy consumption (PJ)		2009	2015	2020	2025	2030	2035	2040	2045	2050
Industry - fuels	World	71134	82832	84784	83378	81806	79858	76952	74208	71502
Industry - fuels	OECD Americas	10475	11530	11138	10611	10098	9549	9071	8691	8357
Industry - fuels	OECD Asia Oceania	4308	4548	4429	4220	4014	3787	3525	3273	3031
Industry - fuels	OECD Europe	7548	8541	8330	8046	7767	7476	7077	6805	6645
Industry - fuels	Transition Economies	6290	6451	6479	6335	6160	6009	5768	5511	5236
Industry - fuels	India	4354	5569	6227	6670	7041	7376	7514	7645	7753
Industry - fuels	China	21223	26202	26954	25585	24245	22706	21089	19546	17942
Industry - fuels	Rest of developing Asia	5454	6803	7572	7946	8256	8526	8500	8388	8242
Industry - fuels	Latin America	4612	5406	5551	5606	5627	5616	5474	5296	5109
Industry - fuels	Middle East	4176	4790	5098	5242	5364	5456	5477	5496	5513
Industry - fuels	Africa	2695	2992	3004	3117	3235	3358	3455	3555	3674

Final energy consumption (PJ)		2009	2015	2020	2025	2030	2035	2040	2045	2050
Industry - electricity	World	24265	31304	35177	37436	39379	41349	41749	42094	42274
Industry - electricity	OECD Americas	3972	4584	4604	4511	4416	4272	4152	4033	3915
Industry - electricity	OECD Asia Oceania	2077	2440	2507	2488	2466	2420	2322	2227	2135
Industry - electricity	OECD Europe	3974	4488	4531	4515	4493	4436	4327	4219	4112
Industry - electricity	Transition Economies	1860	2217	2398	2514	2610	2714	2774	2829	2880
Industry - electricity	India	1175	1685	2118	2535	2908	3349	3640	3960	4316
Industry - electricity	China	7341	11184	13701	14968	16020	17069	16905	16613	16074
Industry - electricity	Rest of developing Asia	1395	1792	2094	2354	2591	2864	3069	3290	3516
Industry - electricity	Latin America	1210	1444	1574	1677	1767	1852	1933	2017	2102
Industry - electricity	Middle East	437	538	626	718	801	894	969	1050	1137
Industry - electricity	Africa	823	932	1023	1157	1308	1479	1656	1855	2086

Final energy consumption (PJ)		2009	2015	2020	2025	2030	2035	2040	2045	2050
Other - fuels	World	91303	95852	95314	94046	92768	91483	89372	87428	85797
Other - fuels	OECD Americas	13163	13068	12935	12850	12763	12835	12832	12829	12826
Other - fuels	OECD Asia Ocear	3925	4168	4114	4044	3973	3920	3747	3581	3423
Other - fuels	OECD Europe	14942	15451	14915	14254	13606	13013	12153	11351	10601
Other - fuels	Transition Econon	9654	10024	9879	9610	9322	9085	8675	8283	7909
Other - fuels	India	7598	8040	8195	8188	8174	8123	8031	7941	7859
Other - fuels	China	16256	17515	17149	16348	15572	14655	13889	13257	12820
Other - fuels	Rest of developing	8001	8490	8750	8878	8997	9012	8935	8800	8634
Other - fuels	Latin America	2940	3216	3257	3283	3303	3308	3273	3238	3203
Other - fuels	Middle East	2821	3131	3272	3371	3454	3537	3575	3614	3653
Other - fuels	Africa	12004	12749	12848	13219	13601	13995	14262	14534	14868

Final energy consumption (PJ)		2009	2015	2020	2025	2030	2035	2040	2045	2050
Other - electricity	World	34933	39577	42656	45191	47388	50003	50640	51401	52255
Other - electricity	OECD Americas	11733	12169	12108	12013	11868	11677	11209	10760	10330
Other - electricity	OECD Asia Ocear	3571	3759	3681	3571	3457	3352	3123	2910	2712
Other - electricity	OECD Europe	6603	6836	6843	6828	6778	6700	6337	5993	5669
Other - electricity	Transition Econon	1923	2015	2184	2304	2409	2514	2570	2628	2687
Other - electricity	India	1309	1784	2235	2763	3258	3928	4293	4691	5132
Other - electricity	China	3547	5480	6937	7723	8371	9012	9002	8903	8656
Other - electricity	Rest of developing	1819	2260	2694	3262	3768	4464	4932	5413	5918
Other - electricity	Latin America	1686	1891	2035	2185	2315	2476	2585	2698	2816
Other - electricity	Middle East	1720	2145	2433	2749	3026	3333	3569	3822	4092
Other - electricity	Africa	1022	1237	1505	1793	2137	2546	3020	3582	4244

Table 17 Breakdown residential electricity consumption by end use (IEA, 2009b)

	Australia in 2005	EU-15 in 2004	Japan in 2005	Mexico in 2005	Brazil in 2005	India in 2007	US in 2005
Water heating	23%	9%	6%	-	22%	-	8%
Space heating	7%	26%	8%	-		-	7%
Space cooling	6%	1%	5%	0-39%	20%	45% (34% fans)	18%
Refrigeration	15%	15%	-	29%	29% (freezer 5%)	13%	11% (2% freezers)
Clothes washers	1%	8%		4-5%	-	-	1%
Clothes dryers	1%			-	-	-	5%
Dishwashers	1%			-	-	-	2%
Cooking	6%	7%	4%	-	-	-	3%
Home entertainment	10%	9%	-	9-13%	11%	4%	6%
ICT	4%	1%		-	-	-	1%
Pools and spas	3%	-		-	-	-	-
Lighting	13%	12%		10-40%	14%	28%	16%
Standby	4%	-		-	-		-
Miscellaneous/ unknown	6%	12%	77%	9-13%	3%	10%	22%

Table 18 Breakdown electricity consumption in commerce and public services by end use

	US in 2005 (US EPA, 2006)	Canada in 2004 (IEA, 2007)	UK in 2004 (IEA. 2007)	China in 2000 (IPCC, 2007a)
Water heating	4%			13%
Space heating	6%	8%	14%	
Space cooling	16%	13%	10%	37%
Ventilation	8%			
Refrigeration	9%			
Cooking	1%			
Office equipment	12%			
Lighting	35%	25%	41%	
Standby	-			
Miscellaneous/ unknown	9%	55%	35%	50%

Table 19 Included measures and key assumptions for investment costs (UBA, 2009)

Sector	Measure	Investment costs (additional)	Energy savings	Life-time (yr)
Transport	Hybrid passenger cars	➢ 2000-2500 USD for petrol hybrid ➢ 5000-5500 USD for hybrid diesel [Frost and Sullivan, 2008 and TNO et. al, 2006]	➢ Average mileage 12,500 km per year OECD Europe (IEA/SMP, 2004). ➢ Default car 13 km /litre g.e. for OECD Europe (IEA/SMP, 2004). ➢ Hybrid car 20 km /litre g.e. (Toyota, 2008).	10
	Weight reduction of passenger cars	➢ 2185 € (diesel) – 1619 € (petrol) [TNO et. al, 2006 and JRC, 2008] As average we take 1800 €	➢ 18% savings (TNO et. al, 2006 and JRC, 2008) ➢ Average mileage 12,500 km per year OECD Europe (IEA/SMP, 2004). ➢ Default car 13 km /litre g.e. for OECD Europe (IEA/SMP, 2004).	10
	Hybrid buses	Additional investment costs: 150,000 – 200,000 US$ (EESI 2006) As average we take 175,000US$ Additional maintenance costs: 0.02 US$/mile (EESI 2006)	➢ Travel per vehicle: 60,000 km per year OECD Europe ➢ Improve of efficiency: 25 – 45% → as average 35% (IEA SMP, 2004) ➢ Default bus 3.03 km/l OECD Europe (IEA SMP, 2004)	10
	Trucks	Improved aerodynamics, Tyre inflation control (TPMS), Use of wide-based tires, Reduce engine idling and Driver training: 8000 € (US EPA, 2008)	➢ 13% savings (US EPA, 2008) ➢ Average mileage 60,000 km per year OECD Europe (IEA/SMP, 2004). ➢ Default truck 1.6 MJ/t.km for OECD Europe (IEA/SMP, 2004). ➢ Average truck load 8 tonnes for OECD Europe (IEA/SMP, 2004).	10
	Air transport	Improved aerodynamics, Advanced engines, Improved Air Traffic Management (ATM), Further operational measures: 1.4 mln EUR (IPCC, 2007 and IPTS, 2008)	➢ 30% (IPCC (2007) and IPTS (2008)) ➢ 2.6 MJ/p.km in OECD Europe (IEA/SMP, 2004). ➢ Number of passenger per aircraft 300 (assumption). ➢ Mileage 400,000 km per year (assumption).	10
Buildings	Zero-energy buildings – new buildings	65 €/m^2 based on 5-8% higher price as new buildings (standard buildings costs of 1,000€ per m^2) [Passivehaus Institut, Darmstadt]	➢ Energy demand zero-energy house: ➢ 54 MJ/m^2a space heating demand (Passivehaus Institut, Darmstadt) ➢ The energy demand for average new houses equals 270 MJ/m^2a in EU27 (Harmelink, 2008). ➢ Relative improvement potential in EU27 (63% for new buildings).	25
	Roof insulation - existing buildings	30 €/m^2 (Boermans and Petersdorff, 2007)	➢ Existing roofs of buildings built before 1975 in moderate climate EU-27: 1.5 W/m^2K ➢ After insulation in moderate climate: 0.17 W/m^2K ➢ Heat degree days 2900 Kd/a in OECD Europe (Boermans and Petersdorff (2007) for EU27) ➢ Average roof area 43 m^2 for OECD Europe	30

			(0.5*average area dwelling; 85 m^2 in EU27 (Ecofys, 2008))	
	Wall insulation - existing buildings	51 €/m^2 (Boermans and Petersdorff, 2007)	➢ Existing walls of buildings built before 1975 in moderate climate EU27: 1.5 W/m²K ➢ After insulation in moderate climate: 0.22 W/m²K (Boermans and Petersdorff, 2007) ➢ Heat degree days 2900 Kd/a in OECD Europe (Boermans and Petersdorff (2007) for EU27). ➢ Average wall surface is 60 m^2 for OECD Europe (0.7*average area dwelling; is 85 m^2 in EU27 (Ecofys, 2008)).	30
	Floor insulation - existing buildings	26 €/m^2 (Boermans and Petersdorff, 2007)	➢ Existing floors of buildings built before 1975 in moderate climate EU27: 1.2 W/m²K ➢ After insulation in moderate climate: 0.28 W/m²K (Boermans and Petersdorff, 2007) ➢ Heat degree days 2900 Kd/a in OECD Europe (Boermans and Petersdorff (2007) for EU27). ➢ Average floor area is 43 m^2 for OECD Europe (0.5*average area dwelling; is 85 m2 in EU27 (Ecofys, 2008))	30
	Window insulation - existing buildings	130 €/m^2 (Ecofys, 2008)	➢ Existing windows of buildings built before 1975 in moderate climate EU27: 3.5 W/m²K ➢ After insulation in moderate climate: 1.0 W/m²K (Boermans and Petersdorff, 2007) ➢ Heat degree days 2900 Kd/a in OECD Europe (Boermans and Petersdorff (2007) for EU27) ➢ Average window area is 13 m2 for OECD Europe (0.15*average area dwelling; is 85 m2 in EU27 (Ecofys, 2008))	30
	Water saving power heads	Additional investment costs taps per dwelling: 27,- € (Bettgenhäuser et. al, 2008)	➢ 12.5% of energy use shower (Bettgenhäuser et. al, 2008) ➢ Fraction of hot tap water through shower taps of total hot tap water: 50% (Ecofys, 2008) ➢ Energy use for hot tap water: 4.5 GJ/dwelling EU27 (Ecofys, 2008)	10
	Substitute incandescent lamps with compact fluorescent lamps (CFL)	0.3 €/ klm for incandescent and 1.0 €/ klm CFL [ISR, 2007 and European Commission, 2008]	➢ Luminous efficacy range: 73 lm/W for CFL and 16 lm/W for incandescent (ISR, 2007 and European Commission, 2008) ➢ Lifespan incandescent lamp: 1,000 h and CFL: 13,000 h (ISR, 2007 and European Commission, 2008) ➢ Hours per year: 1,000 h (assumption)	10
	Efficient air conditioners	Average per 3.5 kW: € 578 Improved per 3.5 kW: € 1,020 [European Commission, 2007b]	➢ COP average: 3.4, COP improved: 5.0 [European Commission, 2007b] ➢ Average load hours air conditioning per year 400 and capacity air conditioner 3.5 kW	15

			(assumption) => Average electricity use air conditioner 1400 kWh/a.	
	Substitute CRT-screens with LCD-screens in offices	210 € for LCD's instead of 73 € for CRT's [European Commission, 2007b]	➢ 32 W for LCD's instead 75W for CRT-screens ➢ 53 kWh/a for LCD's instead of 116 kWh/a for CRT-screens [European Commission, 2007b]	7
	Cold appliances	164 EUR for best practice refrigerator (Ecofys, 2008)	➢ 35% end us energy savings of refrigerator (ICARUS, 2001) ➢ Average energy demand refrigerator 224 kWh/a (Ecofys, 2008)	10
	Washing machines	136 EUR for best practice washing machine (ISR, 2007)	➢ 13% end us energy savings (ICARUS, 2001) ➢ Average energy demand washing machine 230 kWh/a (Ecofys, 2008)	10
Industry-iron and steel	Sinter plant heat recovery	➢ Retrofit capital costs 0.66 US$/tonne crude steel ➢ Annual operating cost change 0 US$/tonne crude steel [LBNL, 1997]	➢ Fuel savings 0.12 GJ/tonne crude steel ➢ Electricity savings -0.01 GJ/tonne crude steel [LBNL, 1997]	15
Industry-iron and steel	Hot charging / direct rolling in hot rolling mills	➢ Retrofit capital costs 13.1 US$/tonne crude steel ➢ Annual operating cost change -1.15 US$/tonne crude steel [LBNL, 1997]	➢ Fuel savings 0.52 GJ/tonne crude steel ➢ Electricity savings 0 GJ/tonne crude steel [LBNL, 1997]	20
Industry-iron and steel	Recuperative or regenerative burners in hot rolling mills	➢ Retrofit capital costs 2.2 US$/tonne crude steel ➢ Annual operating cost change 0 US$/tonne crude steel [LBNL, 1997]	➢ Fuel savings 0.61 GJ/tonne crude steel ➢ Electricity savings 0 GJ/tonne crude steel [LBNL, 1997]	15
Industry-iron and steel	Scrap preheating in electric arc furnace	➢ Retrofit capital costs 6.0 US$/tonne crude steel ➢ Annual operating cost change -4.0 US$/tonne crude steel [LBNL, 1997]	➢ Fuel savings -0.70 GJ/tonne crude steel ➢ Electricity savings 0.43 GJ/tonne crude steel [LBNL, 1997]	30
Industry-iron and steel	Near net shape casting (for other than flat products)	➢ Retrofit capital costs 134.3US$/tonne crude steel ➢ Annual operating cost change -31.3 US$/tonne crude steel [LBNL, 1997]	➢ Fuel savings 0.30 GJ/tonne crude steel ➢ Electricity savings 0.19 GJ/tonne crude steel [LBNL, 1997]	20
Industry-iron and steel	Pulverized coal injection to 180 kg/thm in blast furnace	➢ Retrofit capital costs 6.2 US$/tonne crude steel ➢ Annual operating cost change -1.8 US$/tonne crude steel [LBNL, 1997]	➢ Fuel savings 0.69 GJ/tonne crude steel ➢ Electricity savings 0 GJ/tonne crude steel [LBNL, 1997]	20
Industry-iron and steel	BOF gas + sensible heat recovery in basic oxygen furnace	➢ Retrofit capital costs 22.0 US$/tonne crude steel ➢ Annual operating cost change 0 US$/tonne crude steel [LBNL, 1997]	➢ Fuel savings 0.92 GJ/tonne crude steel ➢ Electricity savings 0 GJ/tonne crude steel [LBNL, 1997]	10

Industry – electric motors	Variable speed drives, high efficiency motors and efficient pumps, compressors and fans	De Beer and Phylipsen (2001) estimate additional investment costs to be 20 €/GJ final energy saved annually.	Keulenaer et al (2004) estimate the savings potential for motor systems in the EU to be 40%, of which 30% economic (payback time below 3 years).	10
Industry - Cement	Application of multi-stage preheaters	Investment costs are typically €46/GJ primary energy saved annually (De Beer and Phylipsen, 2001)	Energy savings are typically 0.5 GJ/tonne clinker, which is equivalent to 10-15% of the average energy use of a cement plant (De Beer and Phylipsen, 2001).	20
Industry - Cement	Optimisation of heat recovery in clinker cooling	Investment costs are typically €2/GJ primary energy saved annually (De Beer and Phylipsen, 2001)	Energy savings are typically 0.1 GJ/tonne clinker, which is equivalent to 3% of the average energy use of a cement plant (De Beer and Phylipsen, 2001).	20
Industry - glass	Improved melting technique and furnace design	Investment costs are estimated by De Beer and Phylipsen (2001) to be €25/GJ primary energy saved annually	Typical savings are possible of 30% by measures as multi-pass regenerators, waste heat boilers and insulation of regenerator structure.	
Industry – chemicals	Process integration – pinch analysis	Costs for implementation €20/GJ primary energy saved annually (De Beer and Phylipsen, 2001)	Energy savings are in the order of 5-15% (De Beer and Phylipsen, 2001).	20
Industry – chemicals	Debottlenecking petrochemical plant	Costs for implementation €10/GJ primary energy saved annually (De Beer and Phylipsen, 2001)	Energy savings are in the order of 1-1.5 GJ/tonne ethylene, corresponding to 30% of the typical energy use of a naphtha cracker in Europe (De Beer and Phylipsen, 2001).	20
Industry – chemicals	Advanced reformer for ammonia production	Costs for implementation €65/GJ primary energy saved annually (De Beer and Phylipsen, 2001)	Energy savings are in the order of 3-5 GJ/tonne ammonia, corresponding to 10% of the typical energy use for ammonia production (De Beer and Phylipsen, 2001).	20