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Assessment of bottom-up sectoral and regional mitigation potentials

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ABSTRACT

The greenhouse gas mitigation potential of different economic sectors in three world regions are estimated using a bottom-up approach. These estimates provide updates of the numbers reported in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR4). This study is part of a larger project aimed at comparing greenhouse gas mitigation potentials from bottom-up and top-down approaches. The sectors included in the analysis are energy supply, transport, industry and the residential and service sector. The mitigation potentials range from 11 to 15 $GtCO_2$eq. This is 26–38% of the baseline in 2030 and 47–68% relative to the year 2000. Potential savings are estimated for different cost levels. The total potential at negative costs is estimated at 5–8% relative to the baseline, with the largest share in the residential and service sector and the highest reduction percentage for the transport and industry sectors. These (negative) costs include investment, operation and maintenance and fuel costs and revenues at moderate discount rates of 3–10%. At costs below 100 US$/$tCO_2$, the largest potential reductions in absolute terms are estimated in the energy supply sector, while the transport sector has the lowest reduction potential.

1. Introduction

An important question for climate policy making is how much greenhouse gas (GHG) emissions and energy can be saved, in which sectors and at what costs? Traditionally, two different approaches are used to answer this question: the **bottom-up and the top-down** approach. The bottom-up approach is based on technological and sectoral data and mostly physical indicators; the top-down approach describes processes within the economy as a whole including interactions on the basis of calibrated historical behaviour.

The Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC, 2007) includes both approaches to assess the medium-term sectoral potentials and costs of GHG mitigation. The results of the two approaches were found comparable on the global level. However, at a regional and sectoral level the results could not be compared due to various inconsistencies (Hoogwijk et al., 2008).

This study is part of a project in which bottom-up and top-down assessments of the sectoral and regional mitigation potentials are compared. In this paper the GHG emission reduction potentials are estimated at different costs levels for the timeframe 2030 using the bottom-up approach. A subsequent paper (Van Vuuren et al., 2009a) focuses on the top-down approach and compares the two approaches of bottom-up and top-down.

In this paper technical potential estimates are presented for four cost levels (0, 20, 50 and 100 US$/$tCO_2$) and three world regions (OECD, EIT and non-OECD[1]). Only the technical GHG abatement potentials associated with energy use are considered. Hence, the sectors included are the energy supply, transport, industry and residential and service sector, while the agricultural and forestry sectors are not considered. Further information can be found in the background project report (Hoogwijk et al., 2008).

The paper starts with a description of the general research methodology of the bottom-up approach (Section 2). In Section 3 the sectoral assessments are presented for the different sectors. Section 3.4 describes the energy supply sector and also corrections for possible overlap between sectors. The main findings are presented in Section 4, a discussion and conclusion in Section 5.

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[1] OECD includes all the countries of the Organisation for Economic Co-operation and Development excluding the economies in transition. EIT (Economies in Transition) includes the Eastern European countries as well as the countries formerly part of the Soviet Union. Non-OECD includes all other countries.

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2. Methodology

The general method of the bottom-up approach used in this study can be summarised by the following five steps:

1. Definition of the sector boundaries to avoid overlap between sectors.
2. Construction of the baseline for each sector (see Section 3).
3. Identification of the mitigation measures and related costs for all individual sectors (see Section 3).
4. Assessment of the sectoral mitigation potential at different cost levels for all individual sectors (see Section 3).
5. Aggregation of the sectoral potential to total potential including a correction of double counting potentials (see Section 3).

Below we describe the definitions of the sectors, the type of baselines and mitigation potential included. Detailed description of the assumptions used for the sectoral assessments can be found in Section 3 on transport, residential and service, industry and energy supply sector.

2.1. Sector definitions

2.1.1. Energy supply

The energy supply sector includes emissions from fuel use in centralised power generation and heat supply. It includes emissions from combined heat and power (CHP) if these are included in energy statistics as centralised distribution. Emissions related to extraction and distribution are not included in this sector.

2.1.2. Transport

The transport sector includes emissions from fuel use in passenger and freight transport, such as light duty vehicles (LDV), medium and heavy duty vehicles (MDV and HDV), emissions from public transport, motorcycles and emissions from aviation and navigation both inland and international.

2.1.3. Industry

The industry sector includes emissions from all industrial activities, both from fuel use and from major processes. Refineries are included in the industry sector. Both CO_2 and non-CO_2 emissions are included.

2.1.4. Residential and service[2]

The residential and service sector includes emissions from direct fuel use for space heating, water heating and cooking as well as the indirect electricity-associated emissions from space and water heating, space cooling and conditioning, appliances and lighting. A share of district heating emissions associated with heat supply to buildings is included into the buildings sector baseline but neither other emissions from the district heat sector nor options aimed to improve district heat production and distribution are studied. The research did not cover non-CO_2 emissions in the buildings sector (HFCs, HCFCs and CFCs) because their forecast and potential mitigation were recently reviewed in the IPCC/TEAP report (2005).

[2] The category of non-residential buildings is referred to by different names in the literature, including commercial, service, tertiary, public, office and municipal. In this study, all non-residential buildings are included in the service sector.

2.2. Differences compared to the IPCC AR4 (IPCC, 2007), baseline and sector

This study uses the AR4 analyses as a starting point. This was possible as most of the authors have been directly involved in the cost and potentials analyses for the IPCC AR4. However, in this study several additions have been made in order to make sectors more comparable and the reduction potential more complete.

The baseline used in this study is taken exogenously. For all sectors except the residential and service sector, the World Energy Outlook reference scenario, published in 2004 (IEA, 2004) has been used as the baseline scenario. For the residential and service sector a new baseline is constructed based on different aggregated literature sources (Ürge-Vorsatz and Novikova, 2008). However, in this study, the frozen reference parts are excluded in order to be more comparable to the baselines in other sectors. See Table 1 for an overview on where this study is additional to the AR4.

Sectoral baselines and potential estimates of the present research represent updated versions of those from the IPCC AR4. Table 1 summarizes the main updates which have been added to the initial assessment of each sector. Most of the updates in this paper are in the baseline. For instance, one of the major update in this study is the split between fuel, heat and power. This enables to show energy savings associated with electricity consumption in the end-use sectors or in the energy supply sector. This was one of the major differences with the top-down approach which shows electricity savings in the energy supply sector while the bottom-up approach tends to show these savings in the end-use sectors (Hoogwijk et al., 2008; Van Vuuren et al., 2009a).

2.3. Types of mitigation measures and costs included

This study focuses on the maximum technically deployment potential of energy savings at different carbon cost categories. The marginal costs are social turnkey abatement costs, including investment costs, operation and maintenance and fuel costs and revenues, using a discount rate in the order of 3–10%. The costs should be seen as costs in the timeframe considered using a current currency. In the Stern Review (Stern, 2007) the use of marginal costs is described as discussed. Marginal costs are useful for small changes. For large changes cost increases due to e.g. material shortage or cost decreases due to technological learning influence the costs to a large extend. The costs and the reduction potential in this study is calculated in isolation for all sectors. As such it can be used for decision making, but not to calculate overall societal costs of reductions.

The potential is based on physical and technical constraints as well as of the size of the market. Neither technical costs such as social or market nor non-technical barriers are included. The potential reduction at a sectoral level is estimated for a low and a high range representing the main uncertainties in the assumptions.

2.4. Aggregated mitigation potential

Interactions between the energy supply abatement options, i.e. the implementation of carbon free technologies, and the energy saving measures from the residential and industry sectors can cause double counting in the aggregated mitigation potential. The potential for carbon free power supply reduces if the total energy demand is reduced. At the same time, the CO_2 abatement from energy savings is reduced if the CO_2 emission factor is lowered because of more carbon free technologies. This is further

Table 1
Summary of main baseline characteristics and additions to the approach in IPCC AR4 (IPCC, 2007).

Sector	Baseline	Remark	Additions compared to IPCC AR4
Energy supply	WEO2004	Baseline is split in heat and power	• Ranges of reductions have been updated
Transport	WEO2004 and WBCSD2004	Baseline is split in different transport modes	• MDV, HDV and marine • Biofuel regional differentiation
Residential and service sector	Own baseline	An individual baseline for this sector is used as was done in AR4	• The baselines is corrected for frozen reference scenarios
Industry sector	WEO2004	Baseline is split between heat and power and different industry sub-sectors	• New baseline • Split between electricity and heat • Updated sub categories

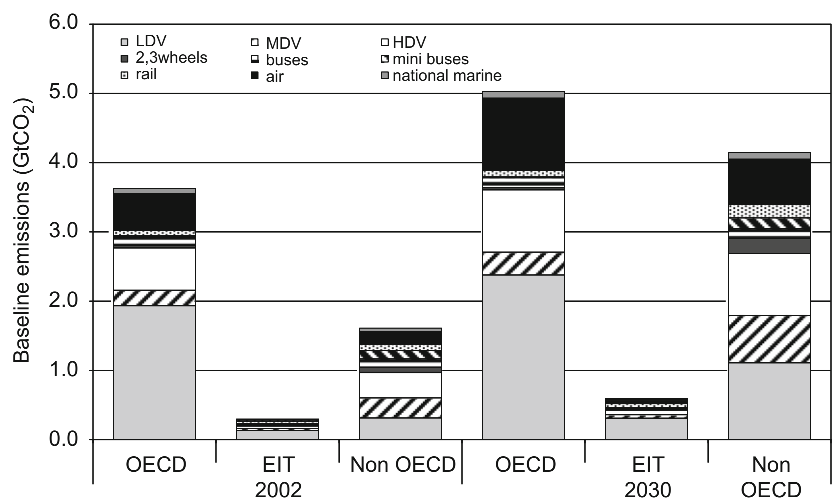

Fig. 1. Baseline emissions of the transport sector in 2002 and 2030.

explained in detail in section 6.2. In the following sections, the data used and the estimates made are described in detail for each sector.

3. Description of methodology, data and results per sector

3.1. Transport sector

3.1.1. Baseline transport sector

The first step of the bottom-up approach was to estimate the baseline for different transport modes. The baseline for LDV is taken directly from the AR4 (IPCC, 2007), which is initially constructed based on the WBCSD scenarios (2004). For the remaining transport modes, data are taken from the WEO2004 (IEA, 2004) and split between the different modes according to the WBCSD scenarios (2004). Fig. 1 shows the resulting baseline scenario broken down by transport modes. As can be observed from this figure, the largest emissions are from light duty vehicles.

The potential reduction is first calculated compared to a frozen-efficiency reference scenario before estimated compared to the WEO2004 baseline. This frozen-efficiency reference scenario is constructed using the growth rates of the WBCSD scenario for the activity indicator (ton-km per year), and assuming a constant energy and emission intensity. The energy and emission intensity is defined as the fuel consumptions per activity indicator.

3.1.2. Mitigation measures transport sector

We calculate the mitigation potential for most transport modes. Medium and heavy duty vehicles (MDV and HDV) for road transport and marine transport is assessed in this study. The potential emission reduction from light duty vehicles (LDVs) and international aviation are taken from the IPCC AR4. In the AR4 the potential reduction at different cost levels were based on the baseline of the WBCSD (2004) and reduction estimates based on recent literature. The cost distribution has been based on various oil price scenarios. The mitigation potential for the other transport modes such as motorcycles and public transport is not included due to lack of comprehensive data in recent literature. The emissions from the modes included contribute 70% to the total transport emissions in 2030. In the description below we focus on the modes that were analysed additionally to the IPCC AR4.

3.1.2.1. Heavy and medium duty vehicle. The potential emission reductions options for HDV and MDV are taken from two sources (Elliott et al., 2006; Lensink and de Wilde, 2007). The results of both studies are summarised in Table 2. The mitigation potential for these measures cannot be aggregated because they overlap. Based on these sources it is assumed that heavy-duty freight can technically improve fuel economy by 39% in 2030 compared to current reference technology. Based on the same sources, it is assumed that medium-duty freight can technically

Table 2
Overview of emission reduction measures for the HDV based on Elliott et al. (2006) and Lensink and de Wilde (2007).

General saving measure	Type of technology	%mpg gain[a]
Rolling resistance	Wide-based tires; pneumatic blowing I	1–3%
Engine	Thermal management, friction reduction, increased peak cylinder pressure, more efficient combustion	2–10%
Auxiliaries	Fuel-cell auxiliaries, electrical auxiliaries	2–6%
Weight	Vehicle mass	8%
Aerodynamics	Cab top deflector, pneumatic blowing, gap closing	2–5%

[a] mpg gain means miles per gallon gain.

improve fuel economy by 50% in 2030 mainly due to the use of hybridization.

The fuel saving is given with a reference to the current fuel economy and current technologies. The WEO2004 baseline already includes technological developments. The values on the potential reduction measures therefore cannot directly be subtracted for the WEO2004 baseline. Instead, the savings are estimated relative to the frozen-efficiency reference scenario as explained in Section 3.1. The savings are subtracted from this frozen-efficiency reference scenario resulting in an alternative scenario with reduced energy use. The difference between the WEO2004 baseline and the reduced reference scenario is taken as the potential emission reduction relative to the baseline.

3.1.2.2. Marine. The potential emission reduction for shipping has also been based on two studies: Lensink and de Wilde (2007) and MARINTEK (2000). Lensink and de Wilde (2007) estimate 20% savings in 2030 for inland navigation as a level that can technically be achieved. With current available technology, efficiency savings up to 30% with respect to the current fleet are possible.

International shipping may result in 28% savings in 2020 due to various reduction technologies and 24% savings in 2020 due to operational measures. The total maximum fuel saving is estimated at 46% (MARINTEK, 2000; Buhaug, 2008). Based on this, we assume 20% for minimum and 46% for maximum savings (with respect to the frozen-efficiency scenario) for international shipping and a 20% minimum and 30% maximum savings for national shipping.

The frozen-efficiency reference scenario for marine is recalculated from the WEO2004 scenario. Assuming WEO2004 already includes (autonomous) efficiency improvements, we corrected the WEO2004 for these improvements, assuming autonomous efficiency improvement of 1% per year. The potential emission reduction is the difference between the WEO2004 baseline and the scenario with the minimum and maximum savings.

3.1.2.3. Biofuels. The AR4 did not specify the regional figures for the potential emission reductions associated with fuel switch to biofuels. In this study, the potential emission reductions from biofuels are included regionally for LDVs, HDVs and MDVs. For all modes it is assumed that of the fuel demand after energy savings, between 5% and 10% biofuels can be blended. The potential emission reductions for the biomass are assumed to substitute between 35% and 60% of CO_2 emissions. This assumption on the CO_2 savings is based on the minimum requirements of the EU RES directive in which a target of 10% for 2020 is agreed at a minimum reduction of 35%. From 2017 onwards all new plants should produce biofuels with a CO_2 saving of at least 60%. A global average blending range of 5–10% is assumed to be a reasonable assumption considering the current US and EU policy and other policy targets. The ranges results in the overall low and high mitigation potential. It should be stated that in order to meet the 10% blending target, it is estimated that around 10 EJ fuel is required. This may be supplied by biofuels without affecting the food consumption (see e.g. Van Vuuren et al., 2009b)

3.1.3. Costs of emission reduction transport sector

For LDV and aviation, the data represented in the AR4 are used. For freight, medium and heavy duty and for shipping the costs are derived from literature.

For freight, the costs were taken from Elliott et al. (2006). Costs for HDV were reported per measure in investment and operation costs in $ per gallon saved. These data are converted to $ per CO_2 avoided for each of the measures. This was done for all individual measures reported by Elliott et al. (2006). This list of measures is used to estimate the cost distribution. The list did not cover the entire range of measures that are included. The cost ranges from Elliott et al. (2006) have been used to assume that 75% of the potential reduction can be achieved at costs below 50 US$/t$CO_2$ and 25% at costs below 100 US$/t$CO_2$. For MDV, the same source reports that at a discount rate of 5% and a fuel price of 2.05 US$/gallon the measures are cost effective after about 3 years. It is therefore assumed that all savings are cost effective.

For shipping no costs were reported except that the costs for all abatement options are "moderate". It is therefore assumed that all costs are below 100 US$/t$CO_2$.

Costs of biofuels have not been calculated separately and the assumption from the IPCC AR4 has been used here, assuming that the biofuels are available at costs below 25 US$/t$CO_2$.

3.1.4. Mitigation potential of the transport sector

The main results for the transport sector are summarised in Table 3. The largest potential is found in energy savings in LDVs. Almost 40% of the total global potential can be realised at negative costs all estimated for the light duty vehicles.

3.2. Residential and service sector

3.2.1. Baseline of the residential and service sector

The method used to calculate the regional and global potential of CO_2 emission reduction in the residential and service sector is described in Ürge-Vorsatz and Novikova (2008). According to this method, the potential was estimated through aggregation of the potential reduction of emission baselines (%) in different countries described in a number of national and regional-focused studies.

As described in Ürge-Vorsatz and Novikova (2008), the global sectoral baseline in 2000–2020 was derived through the aggregation of the baselines of seven regions with similar economic and climate conditions; each regional baseline was estimated through exponential extrapolation of the year 2000 SRES B2 (Nakicenovic et al., 2000) emission data using the respective emission growth rates as provided by the respective studies. The baseline therefore deviates from the WEO2004 baseline. Whereas the baseline calculated in the AR4 IPCC was a mixture of frozen-efficiency and business-as-usual scenarios, the present research has adjusted such a baseline to the business-as-usual conditions only: in cases when studies used a frozen-efficiency baseline, an autonomous efficiency improvement of 1% was applied to adjust them for a business-as-usual case. Assuming that the emission growth rates over the 2020–2030 period will be the same as for the 2000–2020 period, the 2000–2020 emission trends were extrapolated to the period 2020–2030. The baseline forecasted in 2030 is above SRES B2 scenario but below SRES A1 (Nakicenovic et al., 2000) and WEO2004 as illustrated in Fig. 2.

Fig. 3 illustrates the results of the forecast of CO_2 emissions in the buildings sector in the base and target years. The figure attests

Table 3
Main results of the mitigation potential for the transport sector divided per transport mode in Mton CO_2eq per cost category (\$/tCO_2).

	Cost categories	Low				High			
		< 0	0–20	20–50	50–100	< 0	0–20	20–50	50–100
LDV	OECD-EIT	253	270	0	0	523	0	0	48
	EIT	28	0	0	21	28	21	0	0
	Non-OECD	88	30	20	8	146	0	0	0
	Global	369	300	20	29	697	21	0	48
MDV	OECD-EIT	3	0	0	0	138	0	0	0
	EIT	0	0	0	0	15	0	0	0
	Non-OECD	42	0	0	0	307	0	0	0
	Global	45	0	0	0	460	0	0	0
HDV	OECD-EIT	0	0	16	5	0	0	202	67
	EIT	0	0	0	0	0	0	10	3
	Non-OECD	0	0	52	17	0	0	227	76
	Global	0	0	67	22	0	0	439	146
Biofuels HDV and MDV	OECD-EIT	0	0	14	0	0	0	72	0
	EIT	0	0	2	0	0	0	7	0
	Non-OECD	0	0	17	0	0	0	88	0
	Global	0	0	33	0	0	0	168	0
Biofuels LDV	OECD-EIT	0	0	32	0	0	0	111	0
	EIT	0	0	5	0	0	0	16	0
	Non-OECD	0	0	17	0	0	0	58	0
	Global	0	0	53	0	0	0	185	0
Shipping	OECD-EIT	0	0	0	0	0	0	0	7
	EIT	0	0	0	0	0	0	0	0
	Non-OECD	0	0	0	0	0	0	0	7
	Global	0	0	0	0	0	0	0	160
International Aircrafts	OECD-EIT	0	0	0	0	0	0	0	0
	EIT	0	0	0	0	0	0	0	0
	Non-OECD	0	0	0	0	0	0	0	0
	Global	0	0	0	277	0	0	0	277
Total	OECD-EIT	256	270	62	5	661	0	385	122
	EIT	28	0	6	21	43	21	33	4
	Non-OECD	130	30	106	25	453	0	373	82
	Global	414	300	173	328	1157	21	791	632

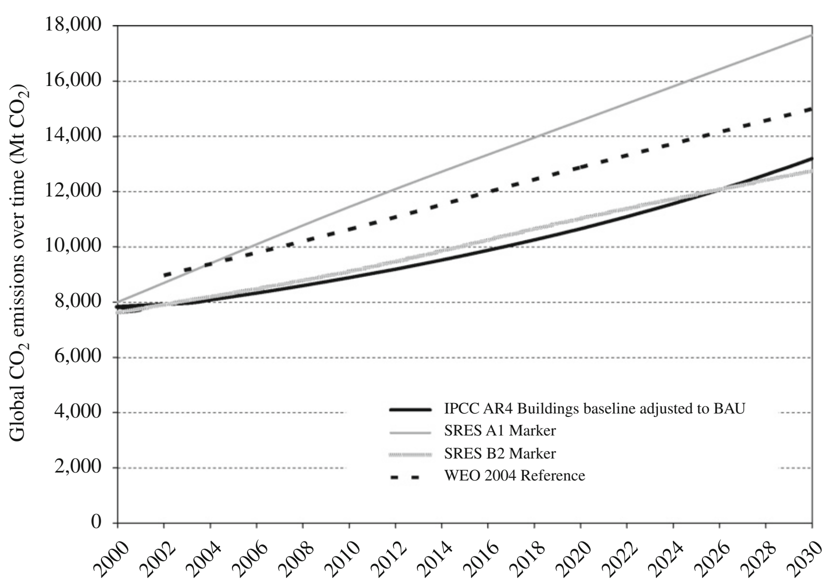

Fig. 2. Comparison of the baseline CO_2 emissions according to the IPCC SRES A1 and B2 scenarios, World Energy Outlook (2004), and the IPCC AR4 Chapter 6 forecast adjusted to the business-as-usual case.

that in 2000 developed countries contributed the largest share to buildings-related CO_2 emissions whereas by 2030 developing countries are projected to take the lead. It is also found that the importance of emissions associated with electricity will grow in developed and developing countries.

3.2.2. Mitigation measures residential and service sector

The regional and global estimates of potential CO_2 emission reductions in buildings relied on the analysis of about 80 bottom-up country- and region-oriented studies as reported in Ürge-Vorsatz and Novikova (2008). Table 4 provides a short summary

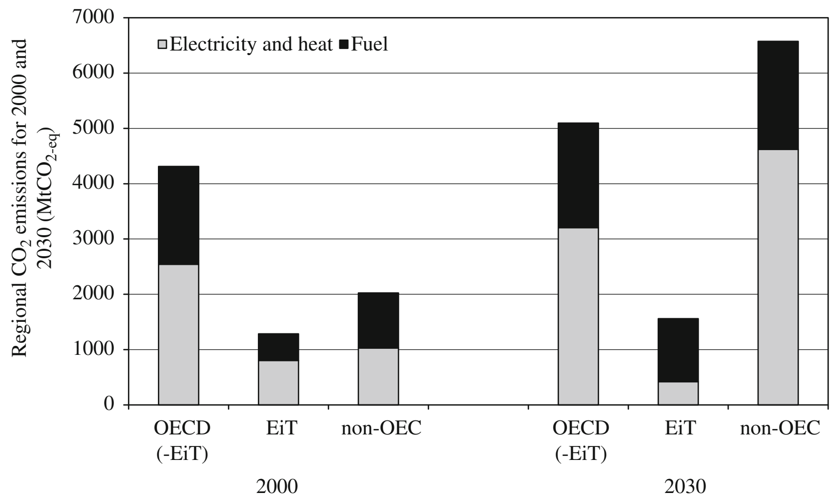

Fig. 3. CO_2 baseline emissions of the buildings sector in different world regions in the base year 2000 and the target year of the projects 2030.

Table 4
Greenhouse gas emissions reduction potential ranges for the buildings stock in 2020[a] by country groups.

Economic region	Countries/country groups reviewed for region	Potential as % of national baseline for buildings[b]	Measures covering the largest potential	Measures providing the cheapest mitigation options
Developed countries	USA, EU-15, Canada, Greece, Australia, Republic of Korea, United Kingdom, Germany, Japan	Technical: 21–54%[c] Economic: 12–25%[d] Market: 15–37%	1. Shell retrofit, inc. insulation, esp. windows and walls 2. Space heating systems and standards for them 3. Efficient lights, esp. shift to compact fluorescent lamp (CFL) and efficient ballasts	1. Appliances such as efficient TVs and peripheries (both on-mode and standby), refrigerators and freezers, followed by ventilators and air-conditioners 2. Water heating equipment 3. Lighting best practices
Economies in transition	Hungary, Russia, Poland, Croatia, as a group: Latvia, Lithuania, Estonia, Slovakia, Slovenia, Hungary, Malta, Cyprus, Poland, the Czech Republic	Technical: 26–47%[e] Economic: 13[f]–37% Market: 14%	1. Pre- and post-insulation and replacement of building components, esp. windows 2. Efficient lighting, esp. shift to CFLs 3. Efficient appliances such as refrigerators and water heaters	1. Efficient lighting and its controls 2. Water and space heating control systems 3. Retrofit and replacement of building components, esp. windows
Developing countries	Myanmar, India, Indonesia, Argentine, Brazil, China, Ecuador, Thailand, Pakistan, South Africa	Technical: 18–41% Economic: 13–52%[g] Market: 23%	1. Efficient lights, esp. shift to CFLs, light retrofit, and kerosene lamps 2. Various types of improved cook stoves, esp. biomass stoves, followed by LPG and kerosene stoves 3. Efficient appliances such as air-conditioners and refrigerators	1. Improved lights, esp. shift to CFLs light retrofit, and efficient kerosene lamps 2. Various types of improved cook stoves, esp. biomass based, followed by kerosene stoves 3. Efficient electric appliances such as refrigerators and air-conditioners

Note: The detailed description of the studies, which are the input into the table, and their references are discussed in Ürge-Vorsatz and Novikova (2008).

[a] Except for EU-15, Greece, Canada, India, and Russia, for which the target year was 2010, and Hungary, Ecuador, and South Africa, for which the target was 2030.
[b] The fact that the market potential is higher than the economic potential for developed countries is explained by limitation of studies considering only one type of potential so information for some studies likely having higher economic potential is missing.
[c] Both for 2010, if the approximate formula $Potential_{2020} = 1-(1-Potential_{2010})^{20/10}$ is used to extrapolate the potential as percentage of the baseline into the future (the year 2000 is assumed as a start year), this interval would be 38–79%.
[d] Both for 2010, if extrapolation formula suggested above is used, this interval would be 22–44%.
[e] The last figure is for 2010, corresponds to 72% in 2020 if the extrapolation formula above is used.
[f] The first figure corresponds to 24% in 2020 if the extrapolation formula above is used.
[g] The last figure is for 2030, corresponds to 38% in 2020 if the extrapolation formula suggested above is applied to derive the intermediate potential.

of the analysis and reports ranges of the estimates of different types of CO_2 mitigation potential in different world regions and countries from the implementation of mitigations options. The table also ranks the options in terms of the size of potential and its mitigation cost. It should be noted that for each country assessed, the number and types of measures are different since they were provided by different reports, i.e. different discount rates, type of costs included and type of options. In total, more than 150 measures were assessed with on average 5–10 options per country study.

Table 4 concludes that efficient lighting is both cost-effective and represents a significant potential for emission reductions in all world regions. In developing countries, efficient stoves rank second, while the second-place measures differ in transition economies and industrialized countries depending on climatic and geographic region.

3.2.3. Global figures in cost ranges for residential and service sector

The global potential estimates as a percentage of the CO_2 baseline emissions were calculated based on the set of selected country/regional studies as described in the previous section. A CO_2 potential as a percentage of the baseline in the respective cost categories were calculated using the method of a population weighted average potential in the subregions for each cost category, and for each world regions, see Ürge-Vorsatz and Novikova (2008). Since there were a limited number of studies looking at 2030, the potential estimates in this year were derived by extrapolating the 2020 figures to 2030 as described in Ürge-Vorsatz and Novikova (2008).

It was found that globally approximately 37% of the sectoral baseline emissions can be avoided at negative costs in 2030 through mitigation measures. Additionally, at least 4% of baseline emissions can be avoided at costs of up to 20 US$/t$CO_2$, and 5% more if costs up to 100 US$/t$CO_2$ are considered. These estimates represent a potential reduction of app. 4.9, 5.4 and 6.0 billion tons of CO_2eq. in 2020, at zero, 20 and 100 US$/t$CO_2$, respectively, assuming the baseline developed on the basis of the reviewed studies. Due to the numerous opportunities at low costs, the high-cost potential has been assessed by few studies, and therefore the high cost potential is underestimated. It should be noted, that due to the limited number of demand-side end-use efficiency options considered by the studies, the omission of non-technological options, the often significant co-benefits, as well as the exclusion of advanced integrated highly efficient buildings, the technical potential is likely to be higher. The results of the calculations by region, by fuel/electricity source, and by cost category are presented in Table 5 and Fig. 4.

Table 5
Potential for CO_2 emission reductions in buildings globally and by country group in 2030.

Region	Type of energy savings	Baseline emissions in 2030, Mtons CO_2	Mitigation potentials split into sources in cost categories in 2030, Mtons CO_2			
			< 0 ($/t$CO_2$)	0–20 ($/t$CO_2$)	20–100 ($/t$CO_2$)	< 100 ($/t$CO_2$)
Global	Total	13.2	4.9	0.50	0.60	6.0
	Electricity	8.2	3.2	0.50	0.05	3.3
	Fuel	5.0	1.8	0.45	0.55	2.8
OECD (-EiT)	Total	5.1	1.4	0.15	0.15	1.7
	Electricity	3.2	0.70	0.00	0.00	0.70
	Fuel	1.9	0.70	0.15	0.15	1.0
EiT	Total	1.6	0.55	0.20	0.40	1.2
	Electricity	0.40	0.30	0.00	0.00	0.30
	Fuel	1.1	0.25	0.20	0.40	0.90
Non-OECD	Total	6.6	3.0	0.50	0.05	3.2
	Electricity	4.6	2.2	0.50	0.05	2.3
	Fuel	2.0	0.80	0.10	0.00	0.90

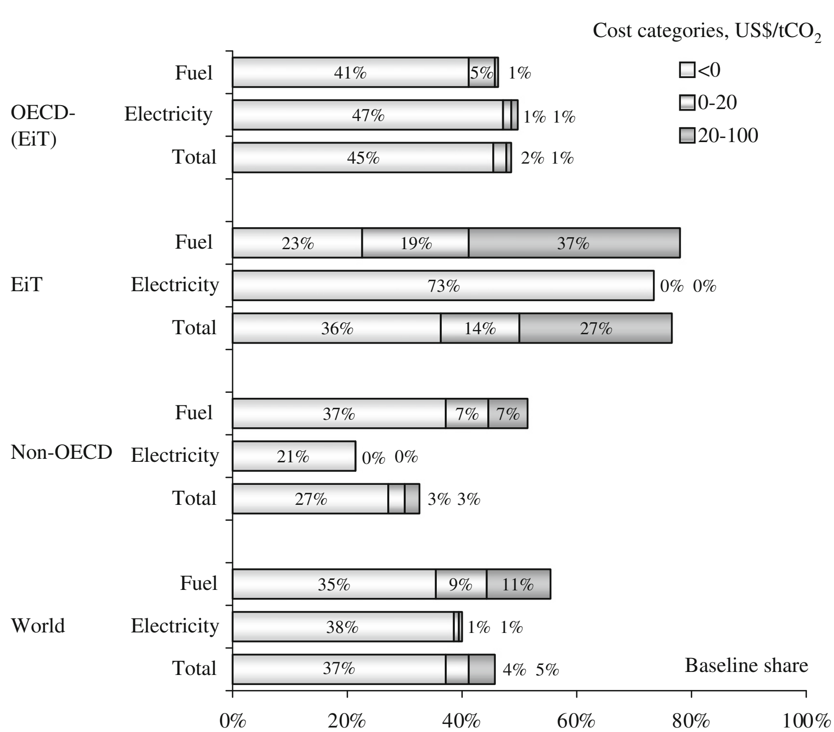

Fig. 4. Potential for CO_2 mitigation in buildings related to electric and fuel end-uses split into cost categories, 2030 (presented as shares of respective fuel- and electricity associated baseline CO_2 emissions).

3.3. Industry sector

3.3.1. Baseline of the industry sector

Similarly to the transport and the energy supply sectors, the WEO2004 reference scenario provided the energy use and CO_2 emissions baseline for the industry sector. However, several modifications were made to first breakdown the industry sector energy use and CO_2 emissions into sub-sectors. Energy use and CO_2 emissions were estimated for seven energy intensive sub-sectors: iron and steel, aluminium, cement, paper, ammonia, ethylene and petroleum product refining. All the other industrial sub-sectors were treated as a remainder, representing light energy intensive industries. Then, CO_2 emission from industrial processes (mostly CO_2 from cement clinker) as well as emissions from non-CO_2 gasses (N_2O, CH_4 and F-gas) based on the IPCC AR4 estimates was added to the WEO baseline scenario. Finally, CO_2 emissions from the petroleum product refining industry were also added to the WEO industry reference scenario, giving that this sub-sector is not included in the industry sector but in the energy supply sector in the WEO2004 data.

To estimate and project energy use for the 7 energy intensive industries (including refining), for each subsector in each region, carbon intensities in terms of carbon emitted per ton of industrial production were estimated through a literature review. Then, commodities production were projected based on the ratio of per capita production and economic development (Price and de la Rue du Can, 2006; Groenenberg, 2005). This enables us to estimate energy use and CO_2 emissions for the 7 energy intensive industries up to 2030, which was then subtracted to the WEO2004 baseline industry projection modified version to estimates energy use and CO_2 emissions projections of the remaining industries.

The baseline of the industry sector per energy intensive sub-sectors is given in Fig. 5. The energy intensive industry baseline scenario is based on expert judgements from literature research. In 2030, the energy intensive industries represent slightly less than in 2005, 55% in 2030 instead of 61% in 2005.

A few updates were performed since the publication of the IPCC AR4 report. First, a new baseline was calculated with data from the WEO2004, instead of A1 and B2 scenarios used in the IPCC AR4 report. Additionally, new data were collected to estimate the energy use for each subsector and each region broken down by fuel type. In this study, CO_2 emissions from fuel use versus electricity use were calculated with new data. Fig. 6 shows the 2030 CO_2 emission projection baseline broken down by source of emissions. Fuel use represents the largest source of emissions, with energy intensive industries representing the largest share (70%). CO_2 emissions from electricity use represent the second largest source with this time light energy intensive industries representing the largest share (also 70%). Finally CO_2 emissions from process cement represent a considerable source of CO_2 emissions with 11% of total industry CO_2 emissions in 2030.

3.3.2. Reduction measures of the industry sector

A large number of potentials is available in the industry sector. They range from sector wide technology improvements, such as the use of more efficient motor systems, to sub-sector specific technology improvements, such as the use of basic oxygen furnace instead of the older technology of open heart furnace in the iron and steel industrial sub-sector. Other measures include the substitution of feedstock, such as the use of blended cement in which clinker is replaced by alternative cementitous materials, thus lowering process emissions; the substitution of fuel, for example the use of biomass in the pulp and paper industry; the

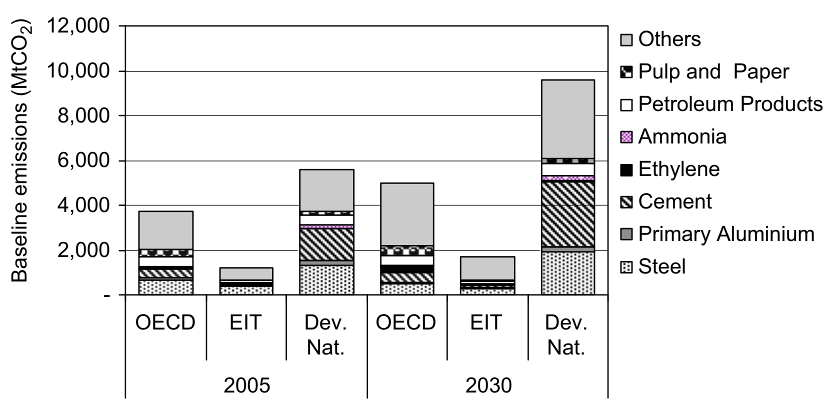

Fig. 5. Baseline emissions of the Industry sector in 2005 and 2030.

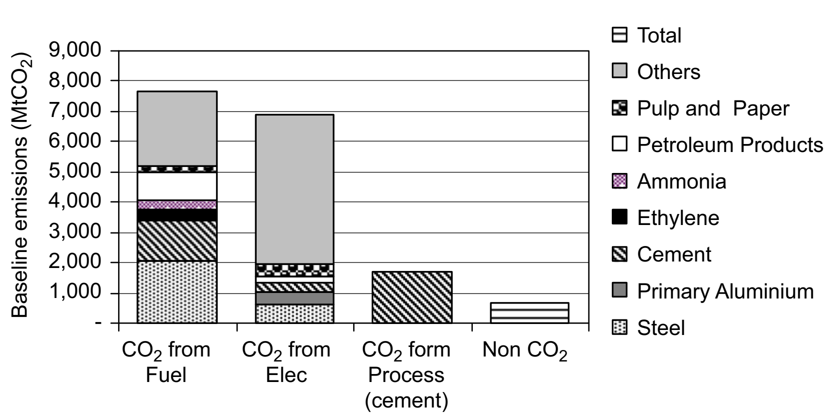

Fig. 6. Baseline emissions of the Industry sector in 2030 broken down by CO_2 source.

capture of CO_2 and its sequestration (CCS) which is more easily applicable in some industries such as ammonia production where emissions is a by-product. Tables 6 and 7 summarizes the potential reduction included in the bottom-up scenario and is based on the work described in the IPCC AR4 chapter on industry (IPCC, 2007) and further described by Worrell et al. (2009).

3.3.3. *Costs of emission reduction in the industry sector*

Costs estimates of individual technical abatement options and comprehensive abatement strategies are reported through a detailed cost curve in the literature for some of the most energy intensive industries sub-sectors (Worrell et al., 2000, 2001). However, this type of detailed analysis is not available for all sectors, and often is only available for a specific country. Other analyses distinguish between theoretical, technical and economical potential where theoretical potential represents achievable energy savings under theoretical considerations of thermodynamics; the technical potential represents achievable energy savings that result from implementing emerging technology, regardless of cost considerations; and economic potential that include efficiency improvement that can be expected under the current market consideration. These types of analyses were used along with expert judgements to assess at which carbon price the potential reduction measure is cost effective.

Table 6
Mitigation percentage estimates for the energy intensive industries.
Source: IPCC, 2007.

	Steel	Primary aluminium	Cement	Ethylene	Ammonia	Petroleum refining	Pulp and paper
Global	15–40%	15–25%	11–40%	20%	25%	10–20%	5–40%
OECD	15–40%	15–25%	11–40%	20%	25%	10–20%	5–40%
EIT	25–40%	15–25%	11–40%	20%	25%	10–20%	5–40%
Dev. Nat.	25–40%	15–25%	11–40%	20%	25%	10–20%	5–40%

Table 7
Mitigation percentage estimates from CCS and for other industries.
Source: IPCC, 2007, calculation updates.

	Carbon, capture and storage				Other industries elec. conservation
	Ammonia	Petroleum Refining	Cement	Steel	
Global	100%	50%	6%	20%	17%
OECD	100%	50%	50%	20%	19%
EIT	100%	50%	50%	20%	23%
Dev. Nat.	100%	50%	50%	20%	20%

3.3.4. *Aggregated mitigation potential of the industry sector*

The total mitigation potential is summarised in Table 8. It can be seen that the potential reduction for fuel, electricity savings and CCS and process emissions are all in the same order of magnitude. The largest share of the all reductions are at costs between 20 and 50 US$/t$CO_2$.

3.4. *Energy supply sector*

3.4.1. *Baseline of the energy supply sector*

For the energy supply sector, the baseline was also taken from the WEO2004 as was done in the IPCC AR4 (IPCC, 2007). For inclusion in this analysis, the baseline should report the fuel mix at a regional scale for primary fuel use for electricity and heat separated, as was done in IPCC AR4 (2007). Therefore the same split was used as in the IPCC AR4 (IPCC, 2007). The total final estimated electricity supply over time is presented in Fig. 7. The total GHG emissions from centralised electricity and heat supply are given in Fig. 8.

Table 8
The total mitigation potential for the different energy carriers for the industry sector in Mton CO_2.

		Baseline (Mton CO_2)	Low				High			
			<0 ($/t$CO_2$)	0–20 ($/t$CO_2$)	20–50 ($/t$CO_2$)	50–100 ($/t$CO_2$)	<0 ($/t$CO_2$)	0–20 ($/t$CO_2$)	20–50 ($/t$CO_2$)	50–100 ($/t$CO_2$)
Electricity	OECD-EIT	2114	0	29	23	100	0	91	53	137
	EIT	857	0	18	22	70	0	28	34	77
	Non-OECD	3903	0	77	102	413	0	117	150	433
	Global	6874	0	125	147	583	0	236	237	647
Fuel (heat)	OECD-EIT	2614	0	91	78	0	0	142	225	0
	EIT	785	0	14	30	0	0	18	91	0
	Non-OECD	4256	0	101	289	0	0	137	924	0
	Global	7655	0	206	398	0	0	298	1240	0
Other (CCS, process)	OECD-EIT	235	0	0	95	27	0	0	204	27
	EIT	79	0	0	39	10	0	0	80	10
	Non-OECD	1406	0	0	301	174	0	0	818	174
	Global	1721	0	0	434	210	0	0	1102	210
Non-CO2	OECD-EIT	305	123	24	8	0	123	24	8	0
	EIT	53	25	2	1	0	25	2	1	0
	Non-OECD	31	93	81	12	0	93	81	12	0
	Global	668	242	107	21	0	242	107	21	0
Total	OECD-EIT	5268	123	144	204	127	123	258	490	164
	EIT	1774	25	35	92	79	25	48	206	86
	non-OECD	9876	93	259	704	587	93	335	1903	607
	Global	16,918	242	438	999	793	242	640	2599	857

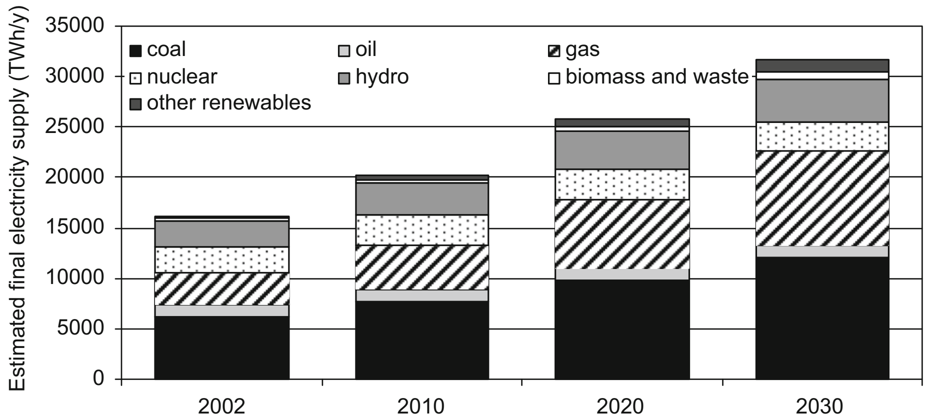

Fig. 7. Total global estimate electricity supply in TWh for different fuel mix based on the WEO2004.

3.4.2. Corrected baseline including energy savings, correction of double counting

The electricity and heat generated in the energy supply sector depends on the demand of the end use sectors, i.e. the residential and commercial sector, the industry sector and to a lower extent the transport sector. In a scenario of lower energy use, due to the introduction of energy efficiency technology deployments, the savings from the end use sectors have first to be deducted from the energy supply baseline scenario before calculating the potential for this sector as explained in Section 2. Adding up would result in double counting of potential reductions.

Therefore, before estimating the GHG mitigation levels from the energy supply sector, the energy savings from the industry and the residential and service sectors have been extracted from the energy supply baseline. The energy savings from these end use sectors were taken as relative potential GHG emission reductions for the electricity production only, see Table 9.

The energy savings from the end use sectors have been subtracted from the baseline using the share of the electricity consumption of the sectors in the total electricity consumption (see Table 9). In this step, it was furthermore assumed that the savings were equally distributed over the different power sources, including low-carbon sources. In fact, it can be expected that electricity savings would reduce relatively more fossil fuel electricity generation compared to generation with low marginal cost such as renewables and nuclear. This is because in the usual operation of electricity systems, low cost fuels are dispatched before high cost fuels. However, as the system operation depends on local conditions, it is not appropriate to consider these here. This approach implies that the potential emission reductions for electricity savings reported here are underestimated. With higher carbon prices, and higher marginal costs of fossil fuels, this underestimation increases.

The result is a baseline corrected for energy savings in the end use sectors as is also shown in Table 10.

3.4.3. Reduction measures of the energy supply sector

The reduction measures included are fuel switching options to low carbon technologies as wind energy, other renewables, biomass energy and nuclear energy. It is assumed that these can be implemented for newly required capacity from 2010 onwards. To estimate the newly required capacity, the revised baseline, i.e. the WEO2004 corrected for energy savings has been used. The required new capacity to 2030 was calculated from (1) additional capacity between 2010 and 2030 to meet new demand and (2) capacity replacement in the same period 2010–2030 after

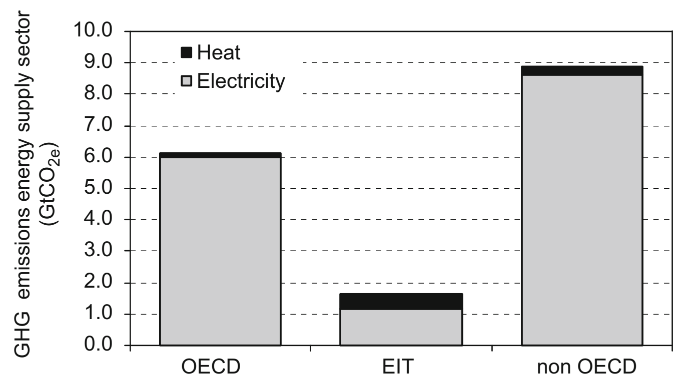

Fig. 8. GHG emissions from the energy supply sector for the centralised heat and the electricity supply.

Table 9
The main assumptions for the correction of the baseline for electricity savings.

	OECD	EIT	Non-OECD
Share of industry sector in total electricity supply (%)	35	52	42
Share of residential and service sector in total electricity supply (%)	65	48	58
Electricity savings in the industrial sector (%)	12	15	17
Electricity savings in the residential sector (%)	16	30	29

retirement. For the retirement an average plant lifetime of 50 years was assumed with linear distribution over the plants.

For the highest range of savings it is assumed that the total new capacity is carbon free by installing either biomass, wind other renewable or nuclear. The technical potential of each resource was checked to assess whether the technical potential is sufficient to supply this combination of technologies. For the lowest range of the potential, the maximum shares of the energy technology perspectives (ETP) 2006 (IEA, 2006) report were used. In the AR4 report, this was used as the highest range of the potential reduction. Here we decided to use this as the lowest range to extract the ranges of the potential to technical maximum and minimum.

3.4.4. Costs of emission reduction of the energy supply sector

The highest share of the potential reduction is assumed to be the deployment of the total additional capacity by carbon free technologies, meaning that all new capacity is carbon free. The contribution of each of the technologies to this potential is

Table 10
The baseline of the energy supply sector from the World Energy Outlook and corrected for the energy savings from residential and industry sector.

	Power mix (WEO2004)		Emissions (CO_2, CH_4, N_2O) of power mix (WEO2004)	Emission reductions in the building sector (WEO2004)	Share of residential g sector in power consumption	Emission reduction in the industry sector (this study)	Share of industry sector in power consumption	Power mix with maximum efficiency improvements	GHG Emissions of power sector after maximum efficiency improvements	Avoided GHG after maximum efficiency improvements	Power that can be substituted (additional +replaced)
	EJ 2010	EJ 2030	Mt CO_2-eq 2030	2030	2030	2030	2030	EJ 2030	Mton CO_2-eq/y 2030	Mton CO_2-eq/y 2030	EJ 2030
OECD-EIT	**100**	**115**	**5977**	**16%**	**65%**	**12%**	**35%**	**99**	**5108**	**869**	**42**
Coal	40	42	3972					36	3395		14
Oil	4	3	214					2	183		0
Gas	19	31	1791					27	1530		16
Nuclear	27	23						20			4
Hydro	5	5						5			2
Biomass and waste	3	5						4			3
Other renew-ables	2	6						5			4
EIT	**17**	**22**	**1173**	**30%**	**48%**	**15%**	**52%**	**17**	**914**	**258**	**8**
Coal	4	4	415					3	324		1
Oil	1	1	58					1	45		0
Gas	7	12	699					10	545		6
Nuclear	3	3						2			0
Hydro	1	1						1			0
Biomass and waste	0	0						0			0
Other renew-ables	0	0						0			0
Non-OECD	**63**	**125**	**8618**	**29%**	**58%**	**17%**	**42%**	**95**	**6541**	**2077**	**60**
Coal	34	66	6300					50	4782		32
Oil	6	8	591					6	449		2
Gas	13	30	1727					23	1310		16
Nuclear	2	6						4			3
Hydro	5	8						6			3
Biomass and waste	1	4						3			2
Other Renew-ables	1	3						2			2

not further quantified. Therefore, the costs are also difficult to quantify. In the IPCC AR4, the costs are taken based on the distribution from the ETP report (IEA, 2006). We decided to use the same cost distribution for both the lowest and the highest range as reported in the AR4. This assumes that the model applied in the ETP report results in the least cost division of technologies.

4. Main findings of the overall mitigation potential

This section presents the main findings of the mitigation potential per sector and region. The aggregated emission baseline for the years 2000 and 2030 is presented in Fig. 9. In this figure the baseline is compared to those of the WEO2004 and the IPCC SRES marker scenarios for the year 2030 (Price and de la Rue du Can, 2006). Please note that for WEO2004 and SRES baselines only CO_2 emissions are included. The growth of the GHG emissions of the aggregated baseline from 2000 to 2030 is 75%. The difference between the A1 baseline and the other baselines is because of the differences in the industry and the residential and service sectors.

In Fig. 10 the main results per sector and cost levels are presented. It can be seen that the energy supply sector has the largest potential at costs below 100 US$/t$CO_2$ and the residential and service sector has the highest cost-effective potential. The total aggregated potential ranges from 10 to 16 GtCO_{2eq} at costs below 100 US$/t$CO_2$.

The data presented in Fig. 10 are based on the end-use sector allocation. When allocating everything to the sectors where the emissions occur (point of emission allocation) the results are different per sector as can be seen in Fig. 11. This type of allocation is used by top-down approaches. In Fig. 11, the results for both allocation approaches are compared with the data from the IPCC AR4. When comparing these figures with the numbers represented in the IPCC AR4, it can be seen that the data have not been altered significantly. For the energy sector the data of this study are higher because the ranges have been revised based on new available data. Interestingly, the transport sector is not increased significantly. The industry sector decreased compared to IPCC AR4. This can only be explained because of the revision in the baseline, the split between fuel and electricity and related to this, the updated data sources that have been used.

In previous figures, the results are presented in absolute terms. In absolute terms the energy supply sector is by far the sector

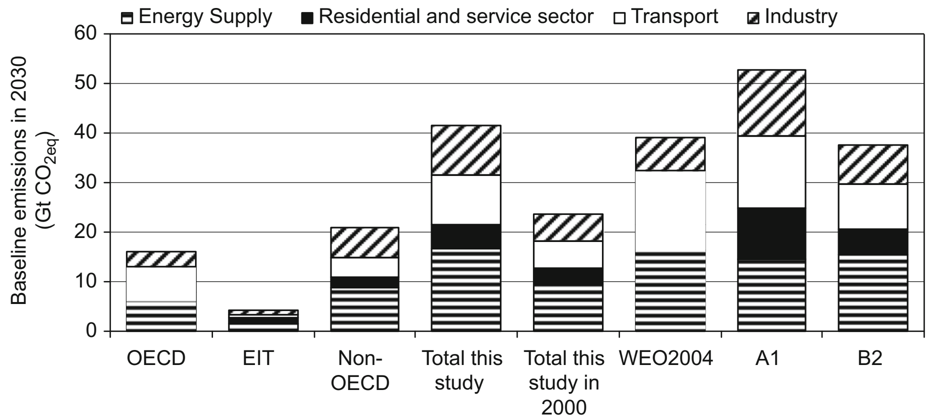

Fig. 9. The aggregated sectoral baseline emissions in comparison with the WEO2004, and the marker SRES A1 and B2 scenarios for the year 2000 and 2030. Please note that for WEO2004 and SRES baselines only CO_2 emissions are included. The allocation to point of emission is done by allocating all emissions from electricity to the energy supply sector. *Source*: This study and Price and de la Rue du Can (2006).

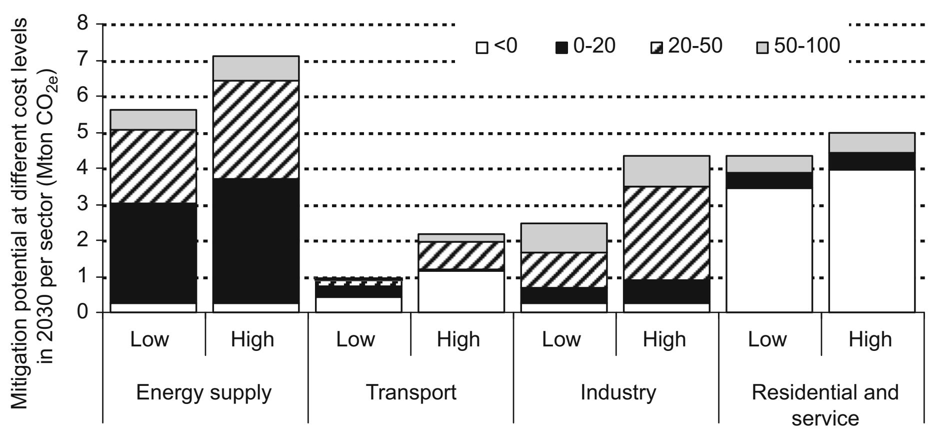

Fig. 10. Main results per sector at different cost levels.

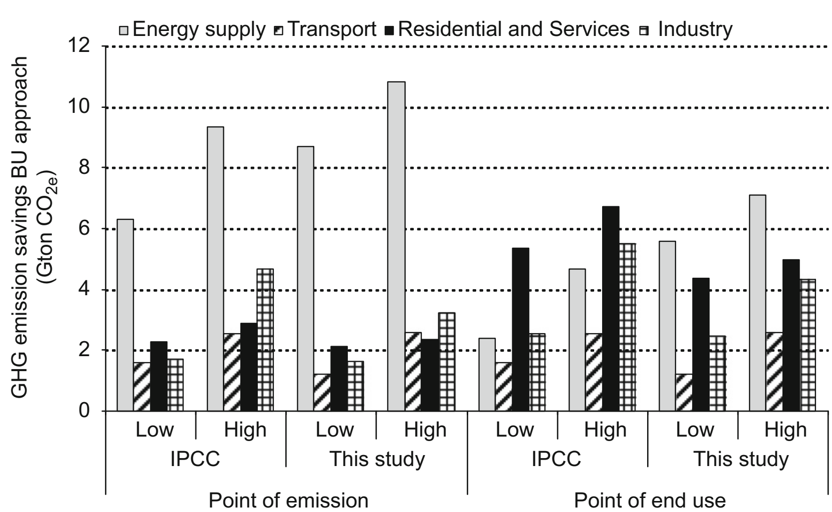

Fig. 11. Main results per sector and aggregated and compared with the AR4 figures.

with the largest potential. When comparing the potential reductions with the baseline, the residential and service sector have the largest potential reduction as can be seen in Fig. 12. This figure also shows the regional differentiation. For most sectors the relative potential reduction is in the same range. The energy supply sector has the highest relative potential. In the residential and service sector in the EIT region the largest potential reduction can be found.

In the AR4 the mitigation potential of the other economic sectors as agriculture, forestry and waste is also estimated. When

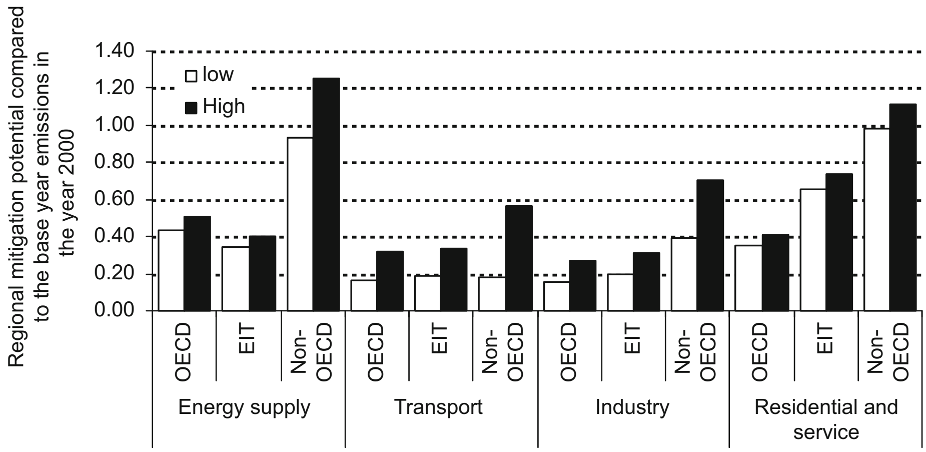

Fig. 12. The sectoral mitigation potential for the different regions relative to the baseline.

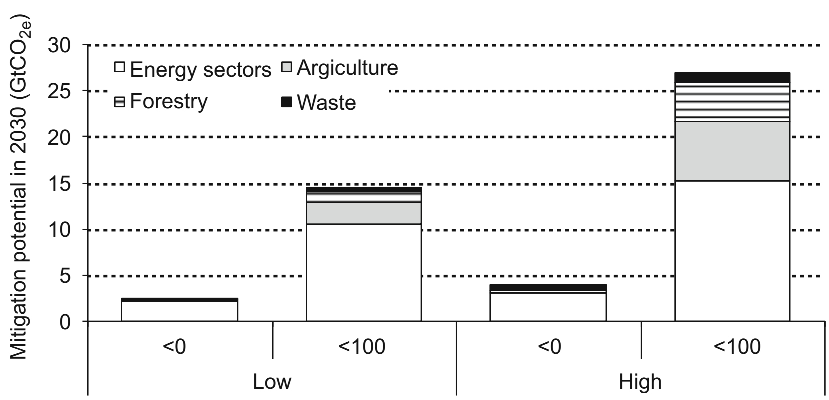

Fig. 13. The mitigation potential in 2030 for different sectors at costs below 0 and 100 US$/t$CO_2$.

adding these potential reductions to the values of the energy related sectors included in this report it can be seen that (see Fig. 13):

- The largest overall potential reductions are estimated for the energy related sectors.
- The most cost effective potentials are estimated for the energy related sectors.
- The ranges of the agriculture and forestry sector are larger than the energy related sectors.
- The total potential reduction ranges from 15 to 28 GtCO_2eq.

5. Discussion and conclusions

5.1. Discussion

The bottom-up approach presented in this paper simulates simple sectoral and regional cost curves of GHG mitigation. It provides GHG abatement potentials for four sectors and three regions at different marginal cost levels. The method is transparent and can be validated and easily adjusted if needed. In addition, the calculations may be refined with more detailed data for sub-sectors and more regional disaggregation without affecting the methodology.

Results of global (baseline) scenarios issued from different international organisations are typically presented at the sector level such as industry, transport or buildings, without further disaggregation. Analysts interested in particular technologies who want to conduct bottom-up energy efficiency scenarios, require more detailed information to understand specific mitigation options in relation to business-as-usual trends. Unfortunately, none of the modelling efforts provide detailed results per sub-sectors and per region.

The World Energy Outlook 2004 scenario was used as baseline. For each sector this baseline was disaggregated to the sub-sectors needed for the bottom-up assessment, using activity indicators such as production units and passenger kilometres. For the residential and service sector, a breakdown based on activity indicator was not possible and a different approach was used. For each sector disaggregating the baseline with exogenous information results in slightly different interpretations per sector. This results in small differences within sectors. However these are not expected to be significant.

In addition to the baseline, different approaches were used to calculate the emission potential reductions per sector. Especially the residential and service sector is treated differently. For the other sectors the potential reductions are estimated based on the activity indicator levels in the baseline; for the residential and service sector the potential reductions are estimated based on country studies aggregated to a regional scale. Most of the country studies estimate potential reductions for the year 2020. The potential estimates were extrapolated to the year 2030. This approach takes into account the technological progress, but the resulting reduction potential in this sector may include part of the reductions of the baseline. Due to this reason, for the residential and service sector the potential estimates for the year 2020 are most reliable to use.

For all sectors the available data on potential reductions at the regional level as well as on the associated costs are limited. For the transport sector the cost distribution was e.g. based on individual measures for the EU and the US applied to all regions. The numbers for the industrial and energy supply sector are also based on reductions and related costs for the OECD region. The residential and service sector has the best regional representation as it is based on different studies on countries level, aggregated to regions.

As also described in IPCC (2007), efficiency penetration and supply options are hindered by a number of barriers, which probably have the strongest effect in the transport sector and the residential and service sector as compared to the other sectors. The potential estimates did not account for the impact of these barriers nor for the rebound effect, which is sometimes considered in top-down studies. This results in reduction potentials at cost effective levels, which is not the case for top-down approaches that do include these barriers and feedbacks in their analyses.

In addition, some reduction options were not included in this study, but should be included in a possible follow-up study. The potentially largest reductions that were not included are:

- reductions in the non-CO_2 emissions in the residential and service sector as well as the energy supply sector,
- reductions in the heat and power generation and distribution sector,
- reductions from CHP options in the industry sector.

5.2. Conclusions

We conclude that the mitigation potential for the energy related sectors ranges from 10 to 15 $GtCO_2$eq. This is 26–38% of the baseline in 2030. This technical potential can be achieved at different cost levels. At negative costs, the largest share can be found in the residential and service sector. The total potential at negative costs is estimated at 6–8% relative to the baseline. Compared to the year 2000 the potential reductions are 47–68%.

The transport sector, which has the lowest emissions, also has the lowest absolute reduction potential. Relative to the baseline, the transport sector is also found to have a low potential reduction, comparable with that of the industry sector. The technological options to reduce GHG emissions in the transport and industry sector are focused mostly at energy efficiency improvements of large technologies with low lifetimes, although biofuels can be used in the transport sector and CCS in the industry. The largest potential reductions are estimated for the energy supply sector. Including also other sectors as waste, agriculture and forestry, it shows that the mitigation potential is the largest for the sectors included in this study. The land use sectors have significant potential but also larger uncertainty ranges.

Findings from this global and regional energy saving potential assessment based on a bottom-up modelling approach sheds light on the technical and economical potential for different sectors and sub-sectors. These findings are key inputs for energy analysts and policy makers. However, as pointed out in the discussion section, some limitations need to be overcome in future work. It is important that the regionally and sectorally specific data is improved. Moreover, the modelling community is urged to develop (baseline) scenarios with more regional and sectoral disaggregation to improve assessments and enable more consistent comparison between regions and sectors.

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