

GREENHOUSE GAS–AIR POLLUTION INTERACTIONS AND SYNERGIES

# GAINS

GHG MITIGATION  
POTENTIALS AND COSTS  
FROM ENERGY USE AND  
INDUSTRIAL SOURCES  
IN ANNEX I COUNTRIES

METHODOLOGY

Janusz Cofala, Pallav Purohit, Peter Rafaj, Zbigniew Klimont

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INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS  
A-2361 LAXENBURG, AUSTRIA <http://gains.iiasa.ac.at>

This report documents the basic methodology of IIASA's GAINS model that has been used for comparing mitigation potentials for energy related and industrial emissions across Annex I Parties.

The following additional information sources are available at <http://gains.iiasa.ac.at/Annex1.html>:

- An interactive [GAINS GHG mitigation efforts calculator](#) that allows online-comparison of mitigation efforts across Annex I Parties. Free access is provided at <http://gains.iiasa.ac.at/MEC>.
- Access to all [input data](#) employed for the calculations for all countries via the on-line version of the GAINS model at <http://gains.iiasa.ac.at/Annex1.html>.

The following report documents the basic methodology of IIASA's GAINS model that has been used for comparing mitigation efforts across Annex I Parties:

- [Potentials and costs for greenhouse gas mitigation in Annex I countries](#). M. Amann et al., 2008

Other reports document details of the methodology for specific sectors:

- [GHG mitigation potentials and costs in the transport sector of Annex I countries](#). J. Borcken-Kleefeld *et al.*, 2008
- [GHG mitigation potentials and costs from land-use, land-use changes and forestry \(LULUCF\) in Annex I countries](#). H. Böttcher *et al.*, 2008
- [Potentials and costs for mitigation of non-CO<sub>2</sub> greenhouse gases in Annex I countries](#). L. Höglund-Isaksson et al., 2008

#### Further information:

Markus Amann  
Atmospheric Pollution and Economic Development Programme  
International Institute for  
Applied Systems Analysis (IIASA)  
Schlossplatz 1  
A-2361 Laxenburg  
Austria

Tel: +43 2236 807 432  
Email: [amann@iiasa.ac.at](mailto:amann@iiasa.ac.at)  
Web: <http://gains.iiasa.ac.at>

The views and opinions expressed herein do not necessarily represent the positions of IIASA or its collaborating and supporting organizations.

# Executive summary

Mitigation efforts and investments over the next two to three decades will have a large impact on opportunities to achieve lower stabilisation levels of greenhouse gas emissions. It will be a formidable challenge to negotiating Parties to arrive at a generally accepted scheme for sharing efforts among Annex I countries that achieves the necessary emission reductions.

**This report provides a documentation of the GAINS methodology that has been developed to compare greenhouse gas mitigation potentials and costs for Annex I countries. In particular, the report specifies options available in the energy sector and explains the approach for exploring the potentials for energy efficiency improvements in the domestic and industrial sectors.**

The methodology identifies the most important demand categories of residential and commercial energy use and of six industrial sectors in the Annex I countries. It quantifies the current implementation rates for a set of specific measures that improve energy efficiency for the various end use categories in such a way, that energy statistics reported for the year 2005 are reproduced with activity data from economic statistics. Thereby, the specific energy intensities of the various countries are determined. Correction for country-specific factors (e.g., climatic conditions, floor space, shares of single and multi-family houses, etc.) enables the assessment of the further technical potential that is available in each country to further improve energy efficiency.

Considering these technical potentials, baseline implementation rates of the various options for improving energy efficiency are determined for the year 2020 in such a way that the projected level of sectoral energy consumption of the baseline energy projection (i.e., the World Energy Outlook 2008 of the International Energy Agency) is matched. This also provides the scope for further improvements that is not assumed as an autonomous development in the baseline projection.

**Access to all input data that have been employed for the calculation is available over the Internet from the [GAINS-Annex I](http://gains.iiasa.ac.at) on-line model.**

## About the authors

Janusz Cofala and his co-authors, Zbigniew Klimont, Pallav Purohit and Peter Rafaj work at the Atmospheric Pollution and Economic Development programme (led by Markus Amann) of the International Institute for Applied Systems Analysis.

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# Glossary

Annex I	List of industrialised countries which are Parties to the UNFCCC
CH <sub>4</sub>	Methane
CO	Carbon monoxide
CO <sub>2</sub>	Carbon dioxide
CO <sub>2</sub> eq	CO <sub>2</sub> -equivalent, i.e., the emissions of greenhouse gases converted into CO <sub>2</sub> equivalent using the 100 years global warming potential
CRF	Common reporting format for submission to the UNFCCC
FAO	Food and Agriculture Organization
FBC	Fluidized bed combustion
GAINS	Greenhouse gas - Air pollution Interactions and Synergies model
GHG	Greenhouse gas
HCFC-22	Chlorodifluoromethane, CHF <sub>2</sub> Cl
HFC	Hydrofluorocarbon
HFC-134a	1,1,1,2-Tetrafluoroethane
HFC-23	Trifluoromethane, CHF <sub>3</sub>
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
Kyoto Protocol	UNFCCC Protocol setting binding GHG emission reduction targets
LULUCF	Land use, land-use change and forestry
N <sub>2</sub> O	Nitrous oxide
NEC directive	National emission ceilings directive
NF <sub>3</sub>	Nitrogen trifluoride
NH <sub>3</sub>	Ammonia
NMVOC	Non-methane volatile organic compounds
NO <sub>x</sub>	Nitrogen oxides
PFC	Perfluorocarbon
PJ	Petajoule
PM	Fine particles in the atmosphere (particulate matter)
SCR	Selective catalytic reduction
SF <sub>6</sub>	Sulphur hexafluoride
SO <sub>2</sub>	Sulphur dioxide
t	Metric tonne
UNFCCC	United Nations Framework Convention on Climate Change
Xe	Xenon

# 1 Introduction

Climate change impacts can be reduced, delayed or avoided by mitigation of greenhouse gases (GHGs). Mitigation efforts and investments over the next two to three decades will have a large impact on opportunities to achieve lower stabilisation levels of greenhouse gas emissions. It will be a formidable challenge to negotiating Parties to arrive at a generally accepted scheme for sharing efforts among Annex I countries that achieves the necessary emission reductions.

The International Institute for Applied Systems Analysis (IIASA) has developed a scientific tool to support the current negotiations. Known as GAINS (Greenhouse gas – Air pollution Interactions and Synergies), the tool not only helps negotiators identify the most cost effective way to reduce GHG emissions, but also allows negotiators to compare mitigation efforts among Parties.

GAINS estimates emission reduction potentials and costs for a range of greenhouse gases and air pollutants and quantifies the resulting impacts on air quality and total greenhouse gas emissions considering the physical and economic interactions between different control measures. As a principle, the analysis employs only such input data that are available in the public domain and that appear credible and consistent in an international perspective. While the IIASA team collaborated with national experts to verify important data and assumptions for individual countries, constraints on time and financial resources did not allow for an extensive validation of all input data.

In brief, the methodology (i) adopts exogenous projections of future economic activities as a starting point, (ii) develops a corresponding baseline projection of greenhouse gas emissions for 2020 with information derived from the national GHG inventories that have been reported by Parties to the UNFCCC for 2005, (iii) estimates, with a bottom-up approach, for each economic sector in each country the potential emission reductions that could be achieved in 2020 and 2030 through application of the available mitigation measures, and (iv) quantifies the associated costs that would emerge for these measures under the specific national conditions. The approach includes all six gases that are included in the Kyoto protocol (i.e., CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, HFCs, PFCs, SF<sub>6</sub>) and covers all anthropogenic sources that are included in the emission reporting of Annex I countries to UNFCCC (i.e., Energy, Industrial Processes, Agriculture, Waste, and from LULUCF).

This report introduces the methodology for assessing the potentials of energy efficiency improvements for the reduction of GHG emissions from energy sector and from the residential, commercial and industrial sectors. Section 2 describes the economic drivers used in the GAINS analysis. Section 3 discusses the approach for the power generation sector and other energy industries. Section 4 presents the methodology for assessing the potential for energy efficiency improvement in the tertiary (residential, commercial, other) sector. Section 5 describes the approach for exploring the scope for efficiency improvements in the industry. These energy efficiency potentials are the basis for calculating GHG mitigation potentials in each sector.

Latest input data that are used for the analysis can be extracted from the GAINS online model at [GAINS-Annex I](#).

## 2 Approach

### 2.1 Major steps

Mitigation potentials for future years are estimated in GAINS through the following steps:

- As a starting point GAINS considers a comprehensive inventory of mitigation measures that could be applied at the different source sectors to reduce emissions of the various greenhouse gases. For each measure the inventory holds information on technical and economic specifications and on key factors that lead to objective differences in mitigation efficiencies, applicability and costs across countries. It also considers (positive or negative) effects on other pollutants. For the mitigation of greenhouse gas emissions, four generic groups of measures are distinguished:
  - End-of-pipe measures that can be applied to reduce the release of emissions without changing the activity level (e.g., CCS, methane recovery, N<sub>2</sub>O, incineration of F-gases, etc.),
  - energy efficiency improvements that reduce the combustion of fossil fuels but deliver the same level of energy services (e.g., improved insulation, higher combustion efficiencies, etc)
  - substitution of high-carbon fuels by fuels with lower carbon content,
  - application of new technologies that produce less greenhouse gas emissions (hybrid vehicles, etc.)
- For each source sector in each country, emissions reported to UNFCCC for 2005 are reconstructed based on statistical information on activity data and emission factors that explicitly consider (i) country-specific circumstances (e.g., climatic conditions, fleet composition, vintage structure of the capital stock, etc.) and (ii) the rate at which mitigation measures that have been identified in the preceding step have been implemented in 2005.
- For each source sector in each country, a baseline emission projection is constructed for 2020 that considers (i) changes in activity levels as specified in the exogenous activity scenario (e.g., the World Energy Outlook), and (ii) changes in emission factors that result either from technological changes that are assumed in the activity projection (e.g., autonomous improvement of energy efficiency) or, where applicable, from the deployment of dedicated mitigation measures that are already laid down in existing national legislation.
- For each of the mitigation measures identified in step 1, the maximum applicability in 2020 is estimated for each sector in each country. The maximum application rate considers structural features in a country (e.g., potentials for fuel substitution, the rate of

turnover of the capital stock, the exclusion of premature scrapping of existing capital, etc.),

- Using sector- and country-specific costs for the mitigation measures (see below), an optimization is carried out for each country that identifies, for a given greenhouse gas reduction target, the portfolio of mitigation measures that achieves the target at least cost. The optimization considers, in addition to the different costs of individual measures,
  - o the demand for (energy) services as specified in the activity projection,
  - o the penetration of mitigation measures that is implied in the activity projection for 2020,
  - o application limits of the additional mitigation measures as identified above,
  - o the scope for replacement of existing infrastructure,
  - o upstream implications of reduced energy demand on the energy supply structure and their economic consequences (e.g., that lower demand for electricity from energy savings in the end use sector allows phase-out of the most inefficient (i.e., GHG intensive) forms of electricity production),
  - o (positive or negative) side-effects on emissions of other greenhouse gases or air pollutants.
  - o However, this optimization does not consider changes in the export and import of electricity or materials, nor the use of flexible instruments to acquire carbon permits abroad.
- As an outcome, such an optimization run provides a detailed portfolio of mitigation measures that would achieve the given emission reduction target at least cost. Conducted for a sequence of gradually tightened emission reduction targets, national cost curves can be derived that describe how costs for greenhouse gas mitigation in a country change over the full range of the mitigation potential.

## 2.2 Mitigation measures

Basically, three groups of measures to reduce greenhouse gas emissions can be distinguished:

- *Behavioural changes* reduce anthropogenic driving forces that generate pollution. Such changes in human activities can be autonomous (e.g., changes in lifestyles), they could be fostered by command-and-control approaches (e.g., legal traffic restrictions), or they can be triggered by economic incentives (e.g., pollution taxes, emission trading systems, etc.). The GAINS concept does not internalize such behavioural responses, but reflects such changes through alternative exogenous scenarios of the driving forces.
- *Structural measures* that supply the same level of (energy) services to the consumer but with less polluting activities. This group includes fuel substitution (e.g., switch

from coal to natural gas) and energy conservation/energy efficiency improvements. The GAINS model introduces such structural changes as explicit control options.

- A wide range of *technical measures* has been developed to capture emissions at their sources before they enter the atmosphere. Emission reductions achieved through these options neither modify the driving forces of emissions nor change the structural composition of energy systems or agricultural activities. GAINS considers several hundred options for greenhouse gases and about 1,500 pollutant-specific end-of-pipe measures for reducing SO<sub>2</sub>, NO<sub>x</sub>, VOC, NH<sub>3</sub> and PM emissions and assesses their application potentials and costs.

Table 2.1: Major groups of structural measures to reduce emissions of air pollutants and greenhouse gases considered in GAINS. For more details consult Klaassen *et al.*, 2005.

Sector	Measure
Power plants	<ul style="list-style-type: none"> <li>• Use of renewables (wind, solar, hydro) instead of fossil fuels.</li> <li>• Gas and biomass fired power plants instead of coal fired plants.</li> <li>• Combined heat and power (CHP) to increase the overall energy system efficiency.</li> <li>• (Efficiency measures that reduce electricity consumption in industry and the residential/commercial sector)</li> </ul>
Residential sector	<ul style="list-style-type: none"> <li>• Energy saving packages (3 stages each) for heating, cooling, air conditioning for <ul style="list-style-type: none"> <li>○ existing houses,</li> <li>○ new houses,</li> <li>○ existing apartments,</li> <li>○ new apartments.</li> </ul> </li> <li>• Energy saving packages (3 stages each) for <ul style="list-style-type: none"> <li>○ water heating,</li> <li>○ cooking,</li> <li>○ lighting,</li> <li>○ small appliances,</li> <li>○ large appliances.</li> </ul> </li> <li>• District heating with CHP instead of residential boilers.</li> </ul>
Commercial sector	<ul style="list-style-type: none"> <li>• Energy saving packages (3 stages each) for heating, cooling, air conditioning for <ul style="list-style-type: none"> <li>○ existing buildings,</li> <li>○ new buildings.</li> </ul> </li> <li>• Energy saving packages (3 stages each) for <ul style="list-style-type: none"> <li>○ water heating</li> <li>○ cooking,</li> <li>○ lighting,</li> <li>○ small appliances,</li> <li>○ large appliances.</li> </ul> </li> <li>• District heating with CHP instead of commercial boilers</li> </ul>
All industries	<ul style="list-style-type: none"> <li>• Gas-fired boilers instead of coal-fired boilers.</li> <li>• CHP instead of industrial boilers.</li> <li>• Carbon capture and storage (CCS) for major emitters.</li> </ul>
Iron and steel	<ul style="list-style-type: none"> <li>• Energy saving packages (3 stages)</li> </ul>
Chemicals	<ul style="list-style-type: none"> <li>• Energy saving packages (3 stages)</li> </ul>
Non-ferrous metals	<ul style="list-style-type: none"> <li>• Energy saving packages (3 stages)</li> </ul>
Non-metallic minerals	<ul style="list-style-type: none"> <li>• Energy saving packages (3 stages)</li> </ul>
Paper and pulp	<ul style="list-style-type: none"> <li>• Energy saving packages (3 stages)</li> </ul>
Other industries	<ul style="list-style-type: none"> <li>• Energy saving packages (3 stages)</li> </ul>

## 2.3 Macroeconomic drivers

The assessment of future mitigation potentials and costs in the GAINS model is based on a baseline projection of economic development and on the implied anthropogenic activities that generate greenhouse gas emissions (i.e., energy consumption, transport demand, industrial production, agricultural activities, etc.). Macroeconomic drivers employed by GAINS are listed in Table 2.1. All financial parameters are expressed in constant prices (Euro 2005). Depending on the purpose of analysis, GDP can be expressed either at market exchange rates (MEX) or at purchasing power parity (PPP). The use of purchasing power parities represents specific conditions of countries with economies in transition, for which the MEX does not properly reflect the real values of output due to price distortions. The use of PPP diminishes erratic effects of fluctuations of currency rates in international financial markets.

Since the GAINS model is not an economic or energy model in itself and therefore does not predict these data endogenously, macro-economic drivers and resulting activity levels for future years are derived from in-depth national/sectoral studies as an input to GAINS. Such exogenous baseline projections are extracted from national energy forecasts prepared by national expert teams, or from international model studies such as the International Energy Agency's (IEA) World Energy Outlook - WEO 2008 (OECD/IEA, 2008) or the scenarios developed with the PRIMES model for the countries of the European Union (Capros *et al.*, 2008).

For an assessment of future emission mitigation potentials, assumptions made in these projections about the future development of population, GDP growth, energy prices, etc. and the resulting energy consumption by economic sector need to be combined with more detailed information on the development of energy-intensive needs in each sector and, in particular, on the possibilities to reduce energy consumption for each need. In addition, such input data have to be tailored to the aggregation used by GAINS.

Values of major economic parameters (GDP, value added by major sector – industry, tertiary, agriculture) are usually available from information that accompanies energy projections. Some sources give more detailed sectoral split of value added. Missing structural information is based on IIASA's analysis of the relative contributions of individual sectors to gross value added. Time trends of these shares were estimated based on historic values (GGDC, 2008, UN, 2008) using regression techniques.

Table 2.1: Macroeconomic parameters in GAINS

Activity	GAINS code
Population, million people	POP
Macroeconomic parameters (in million € 2005):	
• Gross domestic product (market exchange rate)	GDP
• Gross domestic product (purchasing power parity)	GDP_PPP
• Value added - total (at factor cost)	VA_TOT
• Value added - energy (incl. electricity, gas, water supply, mining and quarrying)	VA_ENER
○ of which: mining and quarrying	VA_MINE
○ of which: electricity, gas and water supply	VA_ELGW
• Value added - tertiary sector (incl. agriculture, forestry&logging, fishing, transport, trade, and other)	VA_TERT
○ of which: agriculture, forestry, fishing	VA_AGR
○ of which: commercial sector	VA_COMM
○ of which: transport	VA_TRANS
• Value added - construction sector	VA_CONSTR
• Value added - manufacturing industry -total	VA_IND
• Mineral oil refining, coke and nuclear fuel	VA_ORCKNF
• Value added - basic metals industry	VA_INDMET
○ of which: iron and steel industry	VA_INDISTE
○ of which: non-ferrous metals industry	VA_INDNFME
• Value added - chemicals	VA_INDICHEM
• Value added - non-metallic minerals	VA_INDNMMI
• Value added - pulp, paper, paper products and printing	VA_INDPAPE
○ of which: printing and publishing	VA_PRINT
• Value added - other industries	VA_INDOTH
○ of which: food, beverages, tobacco	VA_INDFOOD
○ of which: textile, leather, footwear	VA_INDTEX
○ of which: wood and wood products	VA_INDWOOD
○ of which: plastics and rubber	VA_INDRUB

### 3 Options in the power generation sector and other energy industries

GAINS contains several dozens power generation technologies, that are characterized by different emissions of greenhouse gases. Thus opportunities exist to decrease greenhouse gases intensity of electricity production. The technologies comprise conventional techniques of power generation from fossil fuels in new plants as well as plants with higher efficiency (e.g., IGCC). Electricity generation from biomass fuels is also included. For each of the generation options carbon capture and storage (CCS) can be applied. Another group of technologies contains power generation from renewable sources other than biomass (geothermal, solar, hydro, wind). In order to increase the overall efficiency of the system, power and heat (steam and hot water) can be generated in combined heat and power (CHP) schemes. Major technologies included in GAINS are listed in Table 3.1.

Besides technologies for power and heat generation, GAINS considers energy saving options in other energy conversion and transmission and distribution systems (refineries, coke plants, transmission and distribution lines). They are represented in the model by up to three efficiency improvement stages for GAINS sectors CON\_COMB and CON\_LOSS.

Data on power generation technologies (generation efficiencies and costs), on the potentials for renewable energy use as well as on the potentials for carbon capture and storage have been recently updated based on available literature (OECD/IEA, 2008, IEA/OECD, 2008). Summary of assumptions made for the needs of GAINS can be found in (Purohit, 2009a,b). Parameters of those technologies (capital investments, operation and maintenance costs, generation efficiencies and plant factors) are available from [GAINS-Annex I](#) on-line. It needs to be stressed, that costs for intermittent power generation technologies (wind, solar) include the investment costs of backup capacity.

Table 3.1 Options in the power generation sector

Name	Abbreviation - fuel type
<b>Fossil fuels fired electricity only plants</b>	
Non - IGCC without CCS - hard coal (brown coal/lignite)	PP_NE_NCS-HC (BC)
Non - IGCC without CCS - heavy fuel oil	PP_NE_NCS-HF
Non - IGCC with CCS - hard coal (brown coal/lignite)	PP_NE_CCS-HC (BC)
Non - IGCC with CCS - heavy fuel oil	PP_NE_CCS-HF
IGCC without CCS - hard coal (brown coal/lignite)	PP_IE_NCS-HC (BC)
IGCC with CCS - hard coal (brown coal/lignite)	PP_IE_CCS-HC (BC)
Without CCS - gas fired	PP_NE_NCS-GAS
With CCS - gas fired	PP_NE_CCS-GAS
<b>Fuelwood and other biomass fired electricity only plants</b>	
Non - IGCC without CCS	PP_NE_NCS-FWD
Non - IGCC with CCS	PP_NE_CCS-FWD
IGCC without CCS	PP_IE_NCS-FWD
IGCC with CCS	PP_IE_CCS-FWD
<b>Fossil fuels fired CHP plants in industry</b>	
Non - IGCC without CCS - hard coal (brown coal/lignite)	PP_NCI_NCS-HC (BC)
Non - IGCC with CCS - hard coal (brown coal/lignite)	PP_NCI_CCS-HC (BC)
IGCC without CCS - hard coal (brown coal/lignite)	PP_ICI_NCS-HC (BC)
IGCC with CCS - hard coal (brown coal/lignite)	PP_ICI_CCS-HC (BC)
Without CCS - heavy fuel oil	PP_NCI_NCS-HF
With CCS - heavy fuel oil	PP_NCI_CCS-HF
Without CCS - natural gas	PP_NCI_NCS-GAS
With CCS - natural gas	PP_NCI_CCS-GAS
<b>Fuelwood and other biomass fired CHP plants in industry</b>	
Non - IGCC without CCS	PP_NCI_NCS-FWD
Non - IGCC with CCS	PP_NCI_CCS-FWD
IGCC without CCS	PP_ICI_NCS-FWD
IGCC with CCS	PP_ICI_CCS-FWD

<b>Fossil fuels fired plants for district heating systems</b>	
Non - IGCC CHP without CCS - hard coal (brown coal/lignite)	PP_NCD_NCS-HC (BC)
Non - IGCC CHP with CCS - hard coal (brown coal/lignite)	PP_NCD_CCS-HC (BC)
Non - IGCC CHP without CCS - natural gas	PP_NCD_NCS-GAS
Non - IGCC CHP with CCS - natural gas	PP_NCD_CCS-GAS
Non - IGCC CHP without CCS - heavy fuel oil	PP_NCD_NCS-HF
Non - IGCC CHP with CCS - heavy fuel oil	PP_NCD_CCS-HF
<b>Fuelwood and other biomass fired plants for district heating systems</b>	
Non - IGCC CHP without CCS	PP_NCD_NCS-FWD
Non - IGCC CHP with CCS	PP_NCD_CCS-FWD
IGCC CHP without CCS	PP_ICD_NCS-FWD
IGCC CHP with CCS	PP_ICD_CCS-FWD
Non IGCC district heat only without CCS	PP_NDO_NCS-FWD
<b>Plants using other renewable sources</b>	
Geothermal power plants	PP-GTH
Hydro power plants	PP-HYD
Solar photovoltaic power plants	PP-SPV
Wind power plants	PP-WND

## 4 Mitigation options in the residential and commercial sectors

An accurate assessment of the potential of energy efficiency improvements in the ‘domestic’ sector, which includes energy consumption of the residential, the commercial and the ‘other’ (e.g., military) sectors requires detailed considerations of different types of energy demand in these sectors. Therefore, GAINS disaggregates energy consumption that is usually provided in energy projections for the ‘domestic sector’ as a whole, into these three sub-sectors. In addition, in each of these sub-sectors several energy needs  $n$  need to be distinguished (Table 4.1).

For the base year (2005), the share of each sub-sector in total sectoral fuel consumption is determined from energy statistics. For future years, the sub-sectoral split of fuel consumption can be obtained from national studies, or if such estimates are not available, the shares of the base year can be maintained as a first approximation.

$$EC_{j,k,f,r} = EC_{j,f,r} * sh_{j,k,f,2005} \quad \text{Equation 4.1}$$

where:

$EC$	fuel consumption
$sh$	fuel share
$j$	sector
$k$	sub-sector
$f$	fuel
$r$	time period.

In the next step, various technologies/options  $t$  for efficiency improvement are specified for each sub-sector and each need. These options also include the “no improvement” case. Each option is characterized by its unit cost  $cst$ , energy demand reduction efficiency  $\Delta$ , and the maximum possible penetration (applicability)  $X^{max}$ . In addition, a cumulative maximum penetration rate for all options available for a given sub-sector or need  $\bar{X}^{max}$  needs to be determined.

Since an assessment of fuel efficiency improvement for each fuel separately would be impractical, the analysis considers two energy types  $c$ : thermal energy ( $TH$ ) and electricity ( $EL$ ). Thermal energy includes all fuel types (coal, oil, gas, biomass) as well as steam and hot water, either produced locally or supplied via the district heating systems.

Once the reduction of the demand for thermal energy and electricity is determined, the demand for each energy carrier belonging to the “thermal” category can be specified, assuming that the structure of fuel consumption remains the same as in the baseline scenario. This is equivalent to an assumption about a proportional reduction of the demand for each energy carrier. On top of it, GAINS considers fuel substitution options, e.g., switch from coal and oil to gas, or switch to district heating or renewable energy (solar, biomass).

The analysis uses data for 2005 as a base year. Projections cover the period 2020 to 2030, with particular emphasis on the year 2020.

The assessment applies a bottom-up approach, starting from a data set on basic energy needs in each sector (Table 4.1). These include space heating and cooling, water heating, lighting, and appliances. Heating, ventilation and air conditioning (HVAC) needs are estimated for existing and new building stock. Also, houses and apartments are treated separately, because the energy intensities for HVAC depend heavily on the building vintage and type. In addition, implementing efficiency measures in new buildings costs only a fraction of costs for retrofitting existing houses. The other needs, which are less depending on the types and age of buildings are determined for an average building/dwelling.

Energy consumption by need  $n$  after implementation of efficiency options can be calculated from the following formula:

$$EC_{j,k,n,c,r} = A_{j,k,n,r} * M_{j,k,n,r} * enin_{j,k,n,c} * \sum_t ((1 - \eta_{j,k,n,c,t}) * X_{j,k,n,t,r}) \quad \text{Equation 4.2}$$

where:

- $n$  energy need type (e.g., space heating)
- $t$  energy efficiency technology/option
- $A_{j,k,n,r}$  value of activity variable used to assess energy consumption for need  $n$  in sub-sector  $k$  of sector  $j$  in time period  $r$
- $M_{j,k,n,r}$  intensity multiplier for need  $n$  in sub-sector  $k$  of sector  $j$  in time period  $r$
- $enin_{j,k,n,c}$  consumption of energy type  $c$  by need  $n$  in sub-sector  $k$  of sector  $j$  in time period  $r$  without energy efficiency measures
- $X_{j,k,n,t,r}$  implementation rate of technology  $t$  for need  $n$  in sub-sector  $k$  of sector  $j$  in time period  $r$
- $\eta_{j,k,n,c,t}$  reduction in consumption of energy type  $c$  used to satisfy need  $n$  in sub-sector  $k$  of sector  $j$  caused by application of technology  $t$ .

Activity variables  $A$  used in the residential and commercial sector are need-specific. They represent either floor space or number of dwellings (housing units). The demand for certain types of energy services is likely to change in the future. For instance, demand for space cooling is expected to increase with rising incomes. Similarly, the use of electronic equipment in households, and in particular of computer equipment, is likely to increase faster than the number of housing units. In turn, the demand for cooking can decrease because of convenience food, more dining out, etc. Changes in the demand for energy services are included through the so-called intensity multipliers  $M$ , which reflect the ratio of the demand per activity unit in the projection year relative to the demand in the base year.

Table 4.1 Specific uses/energy needs in the residential and commercial sectors

Sector/Need	GAINS code	Activity variable	Intensity indicator
<b>Residential sector</b>	RESID		
Heating, ventilation and air conditioning	HVAC	Living space	GJ/m <sup>2</sup>
- Space heating	SPACE_HEAT	Living space	GJ/m <sup>2</sup>
- Space cooling	SPACE_COOL	Living space	GJ/m <sup>2</sup>
Water heating	WATER_HEAT	Housing unit	GJ/h_unit
Cooking	COOKING	Housing unit	GJ/h_unit
Lighting	LIGHTING	Housing unit	GJ/h_unit
Large appliances (refrigerators, freezers, washing machines, dishwashers, dryers)	APPL_LARGE	Housing unit	GJ/h_unit
Small appliances (computers, TV sets, audio and other electronic equipment)	APPL_SMALL	Housing unit	GJ/h_unit
<b>Commercial sector</b>	COM		
Heating, ventilation and air conditioning (HVAC)	HVAC	Building space	GJ/m <sup>2</sup>
- Space heating	SPACE_HEAT	Building space	GJ/m <sup>2</sup>
- Space cooling	SPACE_COOL	Building space	GJ/m <sup>2</sup>
- Space ventilation	SPACE_VENT	Building space	GJ/m <sup>2</sup>
Water heating	WATER_HEAT	Building space	GJ/m <sup>2</sup>
Cooking	COOKING	Building space	GJ/m <sup>2</sup>
Lighting	LIGHTING	Building space	GJ/m <sup>2</sup>
Large appliances (refrigerators, freezers, washing machines, dishwashers, dryers)	APPL_LARGE	Building space	GJ/m <sup>2</sup>
Small appliances (office equipment, other electronic equipment)	APPL_SMALL	Building space	GJ/m <sup>2</sup>
Other needs (not included separately)	OTHER	Building space	GJ/m <sup>2</sup>

Total consumption of energy type  $c$  in sub-sector  $k$  of sector  $j$  in time period  $r$  can be obtained through summing up consumption generated by each need  $n$ :

$$EC_{j,k,c,r} = \sum_n EC_{j,k,n,c,r} \quad \text{Equation 4.3}$$

An important part of the calculation routine is matching the sum of energy consumption for individual needs with the sectoral total in the base year (2005) and in the projection years for the baseline scenario. Energy demand calculated with this bottom-up approach is usually

different from aggregated fuel demand in the baseline scenario. Thus parameters used in the bottom-up calculation (activity levels, energy intensities, uptake of efficiency technologies in the baseline) need to be adjusted so that GAINS reproduces (with a given accuracy) the baseline values. Calibration needs to be done first for the year 2005. This includes modifying data on energy intensities of individual needs, and/or uptake of efficiency measures in the base year. Next, calibration for the projection years occurs. Modifications need to be done in an iterative way until a satisfactory agreement between calculated fuel consumption and historic/projection values is achieved.

$$\left| \overline{EC}_{j,k,c,r} - EC_{j,k,c,r}^{BL} \right| \leq \varepsilon \quad \text{Equation 4.4}$$

where

$\overline{EC}_{j,k,c,r}$  consumption of energy type  $c$  in sub-sector  $k$  of sector  $j$  in time period  $r$  in the baseline scenario,  
 $EC_{j,k,c,r}^{BL}$  calculated energy consumption for the baseline conditions,  
 $\varepsilon$  accuracy limit.

The calibration for the baseline case is performed through side calculations, if possible with participation of national experts.

Further options for reducing energy consumption are determined taking into account the remaining potential (on top of the baseline) for each efficiency option. Energy consumption for the “maximum efficiency” case can be calculated by the optimisation routine of GAINS assuming minimization of CO<sub>2</sub> emissions under the following conditions:

$$X_{j,k,n,t,r} \leq X_{j,k,n,t,r}^{\max}$$

and

$$\sum_t X_{j,k,n,t,r} \leq \overline{X}_{j,k,n,r}^{\max} \quad \text{Equation 4.5}$$

where:

$X_{j,k,n,t,r}^{\max}$  maximum implementation rate (potential) for technology  $t$  used to satisfy need  $n$  in sub-sector  $k$  of sector  $j$  and time period  $r$   
 $\overline{X}_{j,k,n,r}^{\max}$  maximum value of the sum of implementation rates of all technologies used to satisfy need  $n$  in sub-sector  $k$  of sector  $j$  and time period  $r$ .

The difference in energy consumption caused by the implementation of option  $t$  is calculated from the following formula:

$$\Delta EC_{j,k,c,n,t,r} = EC_{j,k,c,n,t,r}^{BL} - EC_{j,k,c,n,t,r} \quad \text{Equation 4.6}$$

Next, cost of implementing option  $t$  for need  $n$  in period  $r$  can be calculated:

$$CST_{j,k,n,t,r} = (I_{j,k,n,t}^{an} + OM_{j,k,n,t}) * \sum_c \Delta EC_{j,k,c,n,t,r} + \sum_c (p_{c,r} * \Delta EC_{j,k,c,n,t,r}) \quad \text{Equation 4.7}$$

where

$CST_{j,k,n,t,r}$	cost of option $t$ in period $r$ ,
$I_{j,k,n,t}^{an}$	annualized capital investments of technology $t$ per GJ of energy saved,
$OM_{j,k,n,t}$	non-fuel operation and maintenance costs of technology $t$ per GJ of energy saved,
$p_{c,r}$	price of energy type $c$ in period $r$ .

Price  $p_{c,r}$  is the weighted average over fuels belonging to energy type  $c$ . Each option can save thermal energy and electricity. In some cases, an option can save thermal energy and increase the use of electricity or the other way round. Thus, investments and non-fuel OM costs need to be given per unit of total energy saved.

Costs of efficiency measures include only additional cost compared with measures/equipment with standard efficiency. Replacement rates take into account standard turnover rates of equipment, consistent with the life times suggested in the European Union's Directive on End Use Energy Efficiency (EC, 2006). No premature scrapping of equipment is assumed.

For each sub-sector/need it is necessary to determine the following input data:

- activity level,
- energy intensity,
- structure of energy consumption in the baseline scenario,
- need-specific effects and costs of energy efficiency measures.

In the residential sector two types of activity variables are considered, i.e., the number of housing units (dwellings) –  $HU$  and their floor space -  $FS$ . HVAC needs are related to floor space. Other needs are calculated per housing unit. Because of different intensities of HVAC needs, dwellings are divided into:

- Existing houses, built before or in 2005,
- new houses, built after 2005,
- existing apartments (pre-2005), and
- new apartments (post-2005).

Historic values of activity levels are based on census data. Projections use results of national studies (if available) or are based on correlations with population and GDP. First, the number of existing housing units for each building type  $b$  (houses or apartments) is determined:

$$HU_{b,r}^{Ex} = HU_{b,2005} * (1 - DR_b)^{(r-2005)} \quad \text{Equation 4.8}$$

$$HU_{b,r}^{Tot} = HU_{b,2005} * (1 + CAGR_b)^{(r-2005)} \quad \text{Equation 4.9}$$

$$HU_{b,r}^{New} = HU_{b,r}^{Tot} - HU_{b,r}^{Ex} \quad \text{Equation 4.10}$$

where:

$b$	dwelling type,
$HU$	number of housing units,

*DR* demolition rate for existing dwellings,  
*CAGR* compound annual growth rate.

In a further step, floor space is calculated. These calculations take into account that new dwellings have usually more floor space than the existing ones, which is included by a floor space multiplier *FSM*:

$$FS_{b,r}^{Ex} = HU_{b,2005}^{Ex} * fs\_hu_{b,2005} \quad \text{Equation 4.11}$$

$$FS_{b,r}^{New} = HU_{b,r}^{New} * fs\_hu_{b,2005} * FSM_b \quad \text{Equation 4.12}$$

where:

*b* – dwelling type  
*FS* – total floor space,  
*fs\_hu* – floor space per housing unit  
*FSM* – floor space multiplier.

Energy use in different countries is different, depending inter alia on ambient temperatures, the average floor space of dwellings, household's sizes and lifestyles (e.g., the number of hours spent at home, different intensities of lighting, frequency of laundering, frequency of cooking at home, etc.). Thus, energy intensities for each need are country-specific.

There are several options to reduce residential energy consumption. For HVAC needs, measures affecting building envelope can be implemented. These include insulation of walls, basement, attic and roof, windows with lower thermal conductivity, as well as measures improving air tightness of building. Besides, more efficient heating/cooling equipment (boilers and air conditioners) may be applied. Finally, important gains can be obtained from better controls of system operation (e.g., programmable thermostats). Since implementation of measures affecting building envelope and thermostats affect the demand for heating and for cooling, they have been combined into HVAC packages. The demand for heating/cooling as well as effects of efficiency measures depend on climatic conditions and are proportional to heating/cooling degree-days. Thus larger countries, with important differences in climatic conditions within the country, have been divided into census regions. Each census region has been assigned to an appropriate climate zone, depending on average cooling- and heating degree-days. Up to three climate zones have been distinguished for each country. The definition of climate zone is country-specific. In addition, different energy consumption structures in different census regions (e.g., availability of natural gas for space heating) have been included in the calculations as constraints.

There are many measures that reduce energy consumption for other needs. These include more efficient water heaters, energy-saving lighting (replacement of incandescent lamps with compact fluorescent lamps and – in a longer-run - with light emitting diodes), more efficient (large and small) appliances as well as reduction of standby losses (Larsen, 2007).

For each need, four levels of energy efficiencies are defined for the GAINS calculation:

- The standard level (Stage 0) reflects conditions without any measures that aim at the reduction of energy consumption.

- Stage 1 assumes implementation of measures meeting the requirements of the “Energy Star” Program (EPA, 2008; Sanchez *et al.*, 2008) or its equivalent in other countries (e.g., “A” class appliances in Europe).
- Stage 2 simulates the effects of a “premium” efficiency level, corresponding to the standards from the Top Runner Program (METI, 2008).
- Stage 3 is in the current version of the model merely a placeholder for future categories.

The assessment of energy intensities in the base case as well as of the reduction potentials from efficiency improvements is based on literature studies, including the on-line calculators of energy demand for households that are available for some countries (e.g., LBNL, 2007; LinzAG, 2008; WienEnergie, 2008). Also, results from national energy models and studies were used to calibrate GAINS (compare AGO, 1999a; AGO, 1999b; APEC, 2006; ECC, 2007; EES, 1999; EIA, 2008a; EIA, 2008b; EIA, 2008c; GovCan, 2008; Kononov, 2008; Kostyukovsky and Shulzhenko, 2008; NRCan, 2008a; NRCan, 2008b; Sharma, 2008; USCB, 2006; Vorsartz-Uerge, 2008). With this information, energy consumption in the base year (2005) as provided in the IEA energy statistics (IEA, 2008a) has been reproduced through adjustment of the penetration rates of various energy efficiency measures in the equations presented above. In particular, the uptake of efficiency measures in 2005 has been assessed so that the calculated energy consumption did not differ by more than 0.5 percent from the data provided in the statistics.

In a second step, the uptake of these measures has been calibration for 2020 in such a way that the energy consumption projected by the IEA Energy Outlook could be reproduced. Again, this was achieved through reasonable adjustments of the main parameters, i.e., the change of the intensity multiplier  $M$  and the uptake of energy efficiency measures.

The resulting uptake of the various measures in the baseline case also determines the scope for further efficiency improvements for each need, taking into account that certain structural limits exist that restrict the faster penetration of additional energy efficiency measures.

The modelling of energy consumption in the commercial sector follows the same principles as for the residential sector. All energy needs in the commercial sector are related to floor space of commercial buildings ( $FS_{COM}$ ). Also for this sector activity projections are taken from national studies (if available) or are based on correlations that have been established against the growth of per capita commercial GDP:

$$FS_{COM,r} = FS_{COM,2005} / POP_{2005} * (1 + fspc\_gdppc_{COM} * (PCGDP_{COM,r} / PCGDP_{COM,2005} - 1)) * POP_r \quad \text{Equation 4.13}$$

where:

- $FS_{COM,r}$  floor space in the commercial sector in period  $r$
- $POP_r$  population in period  $r$ ,
- $fspc\_gdppc_{COM}$  country-specific ratio floor space per capita in the commercial sector to per capita commercial GDP,
- $PCGDP_{COM,r}$  per capita GDP generated in the commercial sector in period  $r$ .

All energy consumption coefficients are related to the area (square meters) of commercial floor space. Historic distribution of energy consumption among needs is based on in-depth studies, (e.g., CSS, 2007). Other steps are similar to the approach for the residential sector. Characteristics of efficiency improvement technologies have been developed based on literature studies (i.a., Bressand *et al.*, 2007; Lechtenbuomer, 2005) and the assessment of collaborating national experts (Kononov, 2008; Kostyukovsky and Shulzhenko, 2008; Sharma, 2008). When commercial sector-specific data were not available, characteristics of costs of energy saving options were derived from data for the residential sector with appropriate scaling. Scaling factors reflect different sizes of buildings and equipment, and thus reduce unit capital investments compared with the equipment used by households.

Assessment for the EU-Member States, as well as for Norway and Switzerland is based on a study by IVL (Astroem *et al.*, 2009).

## 5 Options in manufacturing industry

Potentials and costs of measures in industry in a country heavily depend on the industrial profile. Thus the GAINS assessment is performed for six industrial sub-sectors  $k$ , shown in Table 5.1. The first five include the sectors with the highest energy intensity. Typically, they are responsible for up to two thirds of total industrial final energy consumption. Within each of those five sectors, manufacturing of the most energy-intensive products has been analyzed in detail and the possibility to implement energy saving measures has been assessed. Products included and the methods for estimating their future production levels are discussed in the further part of this section. These products are responsible for 40 to 50 percent of total industrial energy use. The remaining energy consumption was treated in a more aggregated way by relating energy use to the value added of a sector.

Table 5.1 Industrial sub-sectors considered in the GAINS analysis

Sector name	GAINS code
Iron and steel	INDISTE
Non-ferrous metals	INDNFME
Chemicals	INDCHEM
Non-metallic minerals	INDNMMI
Pulp, paper, paper products and printing	INDPAP
Other industries	INDOTH

Analysis of energy intensity by product in each country in the year 2005 provided the starting point for the assessment, based on data of sectoral energy consumption from the available energy statistics. Based on this, changes of energy intensities up to the year 2020 that are consistent with the baseline scenario have been analyzed. Changes in the baseline structure of fuel consumption by sub-sector have been determined from national studies. If such studies were not available, shares found for the base year have been maintained for the future. In both cases the GAINS approach assures that total energy consumption in all industrial sub-sectors equals total industrial consumption in the baseline scenario.

A wide array of options for saving energy exists in industry (IEA, 2008c). Some of them are highly sector and even plant-specific, and analysis of too many details within a global analysis with the GAINS model would not have been practical. Thus the assessment of energy efficiency potentials (on top of the baseline improvement) has been based on:

- Studies on “Best practices” in manufacturing industry (Worrell, 2007), and
- Analysis of changes in the level and structure of industrial energy consumption for the 27 EU countries in response to different carbon prices, as modelled with the PRIMES model (Capros and Mantzos, 2006).

Since the “Best Practice” study refers to energy-intensive products only, the potential for reducing remaining energy consumption in each sector (related to value added) has been estimated assuming that the annual intensity improvement of that part of energy demand will be faster than in the baseline by up to 1.5 percentage points for thermal energy, and by up to 1.0 percentage point for electricity. Costs of the “Best practice” measures are estimated based on international sectoral studies (e.g., Chen *et al.*, 1999; Martin, 2000; Martin *et al.*, 1999; Nilsson, 1996; Worrell, 2000).

For EU-27 results of the PRIMES model were used (Capros and Mantzos, 2006). PRIMES simulates the behaviour of energy producers and consumers in each country, and in particular their reaction to constraints on CO<sub>2</sub> emissions. Measures that can be introduced for industry include energy efficiency improvement as well as fuel and technology switching. The analysis was performed at a rather detailed technological level. PRIMES results are available for each country of the EU for four levels of carbon prices: 0, 20, 90, and 240 €/t CO<sub>2</sub>. Aggregated results of these scenarios for the EU-27 were combined into three steps (Stage 1 to 3) of possible changes in energy consumption induced by changes in carbon prices. Also costs of each step were estimated. Each option affects simultaneously the demand for thermal energy and for electricity. In some sectors, reduced demand for thermal energy is accompanied by a higher demand for electricity or vice versa. In such cases the “reduction efficiency” for one of energy carriers may be negative. Energy consumption related to a carbon price of € 0/t CO<sub>2</sub> served as a “without measures” case.

Energy consumption in sub-sector  $k$  after implementation of efficiency options can be calculated from the following formula:

$$EC_{j,k,c,r} = EC_{j,k,c,r}^{NM} * \sum_t (1 - \eta_{j,k,c,t}) * X_{j,k,t,r} \quad \text{Equation 5.1}$$

where

$t$	energy efficiency technology/option
$EC_{j,k,c,r}$	consumption of energy type $c$ in sub-sector $k$ in time period $r$ after implementation of energy efficiency measures
$EC_{j,k,c,r}^{NM}$	consumption of energy type $c$ in sub-sector $k$ in time period $r$ without efficiency measures.
$X_{j,k,t,r}$	implementation rate of technology $t$ in sub-sector $k$ in time period $r$
$\eta_{j,k,c,t}$	reduction in consumption of energy type $c$ in sub-sector $k$ caused by application of technology $t$ .

Similarly as for the residential and commercial sectors, the uptake of the efficiency improvement stages has been assessed for the baseline scenario in an iterative way until the calculated energy consumption differs from the consumption in the baseline by less than assumed accuracy limit:

$$\left| \overline{EC}_{j,k,c,r} - EC_{j,k,c,r}^{BL} \right| \leq \varepsilon \quad \text{Equation 5.2}$$

where:

$\overline{EC}_{j,k,c,r}$	consumption of energy type $c$ in sub-sector $k$ of sector $j$ in time period $r$ in the baseline scenario
$EC_{j,k,c,r}^{BL}$	calculated energy consumption for the baseline conditions
$\varepsilon$	accuracy limit.

The scope for further reduction of energy consumption is determined through the remaining application potential (on top of the baseline implementation rate) for each efficiency option. Energy consumption for the “maximum mitigation” case can be calculated by the optimisation routine of GAINS assuming minimization of CO<sub>2</sub> emissions under the following conditions:

$$X_{j,k,t} \leq X_{j,k,t}^{\max}$$

and

$$\sum_t X_{j,k,t} \leq \overline{X}_{j,k}^{\max} \quad \text{Equation 5.3}$$

where

$X_{j,k,t}^{\max}$	maximum implementation rate (potential) for technology $t$ in sub-sector $k$ ,
$\overline{X}_{j,k}^{\max}$	maximum value of the sum of implementation rates of all technologies in sub-sector $k$ .

The difference in energy consumption resulting from the implementation of option  $t$  can be calculated as:

$$\Delta EC_{j,k,c,t,r} = EC_{j,k,c,t,r}^{BL} - EC_{j,k,c,t,r} \quad \text{Equation 5.4}$$

As mentioned above, costs of “Best practice” measures are assessed based on technical reports.

Costs of measures in EU-27 are based on PRIMES model results. Assumption has been made that the costs of measures induced in sub-sector  $k$  by a given carbon price are equal to the sum of the difference between energy costs for the cases with and without carbon constraints and the costs of meeting the carbon constraint:

$$cst_{k,t,SAV} = \frac{\sum_f (cst_{k,f} * EC_{k,f} - cst_{k,t,f} * EC_{k,t,f}) + CO2_{pr,t} * (ECO2_k - ECO2_{k,t})}{\sum_f (EC_{k,f} - EC_{k,t,f})} \quad \text{Equation 5.5}$$

where:

$cst_{k,t,SAV}$	cost of measure $t$ induced by carbon price $CO2_{pr,t}$ per GJ of energy saved,
$cst_{k,t,f}, C_{k,f}$	unit cost of fuel $f$ in the scenario with – and without carbon constraint,

$EC_{k,t,f}$ ,  $EC_{k,f}$  consumption of fuel  $f$  in the scenario with – and without carbon constraint,  
 $ECO2_{k,t,r}$ ,  $ECO2_k$  CO<sub>2</sub> emissions in the scenarios with and without carbon constraint.

Total costs of implementing option  $t$  in period  $r$  can be calculated:

$$CST_{j,k,t,r} = cst_{k,t,SAV} * \sum_c \Delta EC_{j,k,c,t,r} \quad \text{Equation 5.6}$$

where:

$CST_{j,k,n,t,r}$  cost of option  $t$  in period  $r$ .

Details of the approach for individual sectors are discussed in the subsequent sections.

## 5.1 Iron and steel industry

The GAINS assessment of the options for improving energy efficiency in the iron and steel industry considers the potentials for changing energy consumption for the most energy-intensive products in the sector. Products included are shown in Table 5.2. The baseline forecast includes structural changes in the sector, like increased scrap use, reduced steel production in open-hearth furnaces, or increased share of thin slab casting. Sectoral energy consumption for the base year (2005) is taken from the IEA statistics.

Table 5.2: Activities in the iron and steel industry

Activity	GAINS code	Unit	Projection method and data sources
Value added	VA_INDISTE	10 <sup>9</sup> €	IEA macro forecast, correlation with industrial GDP, national studies
Raw steel	PR_STEEL_RAW	10 <sup>6</sup> tons	Correlation with value added
Finished products	PR_STEEL_FIN	10 <sup>6</sup> tons	Percentage raw steel production
Scrap supply	PR_SCRAP	10 <sup>6</sup> tons	Depends on dynamics of steel production methods
Coke oven coke	PR_COKE	10 <sup>6</sup> tons	Demand by blast furnaces and sintering processes, demand by other economic sectors plus net exports
Sinter	PR_SINT	10 <sup>6</sup> tons	Correlation with pig iron production
Pellets	PR_PELL	10 <sup>6</sup> tons	Correlation with pig iron production
Pig iron	PR_PIGI	10 <sup>6</sup> tons	Related to steel basic oxygen steel production
Direct reduced iron	PR_DRST	10 <sup>6</sup> tons	National forecasts. If not available, extrapolation of historic trends
Open hearth furnace steel	PR_HEARTH	10 <sup>6</sup> tons	National forecasts. If not available, extrapolation of historic trends
Basic oxygen steel	PR_BAOX	10 <sup>6</sup> tons	Derived from the raw steel balance
Electric arc furnace steel	PR_EARC	10 <sup>6</sup> tons	National forecasts. If not available, extrapolation of historic trends
Casting, rolling finishing	PR_CRFIN	10 <sup>6</sup> tons	Finished products minus thin slab casting
Thin slab casting	PR_THSLCST	10 <sup>6</sup> tons	National forecasts. If not available, extrapolation of historic trends

Since the IEA statistics treat coke use in blast furnaces as an energy transformation process, coke consumption in blast furnaces appears in the statistics as input to the transformation sector, producing blast furnace gas. The energy content of coke used for iron ore reduction and for metal melting appears as coke loss. To obtain a full picture of the energy intensity of the sector, these losses were added to the total consumption of energy in iron and steel industry. Changes of energy intensity were subsequently assessed for the corrected energy consumption. Manufacturing of the products listed in Table 5.2 is typically responsible for more than 90 percent of thermal energy used in iron and steel industry, and for more than two thirds of electricity. For the GAINS assessment, the remaining fuel and energy consumption has been related to the sectoral value added. The energy intensity of the best practices in

manufacturing of iron and steel products was assessed based on EC, 1999 and Worrell, 2007. For the “best practice” case it has been assumed that the intensity of remaining production can improve by up to 1.5 percent/year faster than assumed in the baseline for thermal energy, and by up to 1 percent per year for electricity.

## 5.2 Non-ferrous metals industry

The assessment for this sector includes products shown in Table 5.3. The activity projection for this sector, which is typically not explicitly supplied in the available economic forecasts, is developed based on historic trends and through correlation with sectoral GDP. The most important structural change in this sector is the possibility to increase the share of metals produced from secondary sources (scrap). Base year (2005) consumption is consistent with the IEA statistics. Anticipated baseline rates of efficiency improvements up to 2020 were extracted from national studies and adjusted in such a way that resulting energy consumption matches the value given in the IEA WEO 2008.

Manufacturing of products listed in Table 5.2 is typically responsible for about two thirds of total sectoral energy consumption. The remaining fuel and energy consumption has been related to sectoral value added, and extrapolated into the future on this basis. Energy intensity of the “best practices” in manufacturing of products in this sector was derived from the literature (e.g., Kuckshinrichs *et al.*, 2007). For the “best practice” case it has been assumed that thermal energy intensity of remaining production can improve by up to 1.5 percent per year faster than in the baseline. For electricity, a faster improvement of up to one percent per year was assumed.

Table 5.3: Activities in the non-ferrous metals industry

Activity	GAINS code	Unit	Projection method and data sources
Value added	VA_INDNFME	10 <sup>9</sup> €	IEA macro forecast, correlation with industrial GDP, national studies
Primary aluminium	PR_ALPRIM	10 <sup>6</sup> tons	Correlation with sectoral value added
Secondary aluminium	PR_ALSEC	10 <sup>6</sup> tons	Correlation with sectoral value added
Other metals - primary	PR_OTH_NFME	10 <sup>6</sup> tons	Correlation with sectoral value added
Other metals - secondary	PR_OTH_NFMSEC	10 <sup>6</sup> tons	Correlation with sectoral value added

## 5.3 Basic chemicals industry

The analysis of this sector distinguishes detailed data on a set of energy-intensive products, i.e., for the production of ammonia, ethylene, and chlorine (Table 5.4). These three products consume about 40 percent of total sectoral energy and 20 to 25 percent of electricity. Forecast of activities is based on historic developments and on correlations with sectoral GDP projections. Similarly as for other sectors, the base year (2005) consumption is consistent with the IEA statistics. Rates of efficiency improvement up to 2020 were estimated based on national studies and then adjusted so that the energy consumption figures given in the IEA WEO 2008 report are reproduced. Data on energy intensity of the best practices in manufacturing of bulk chemicals has been extracted from Worrell, 2000. For the “best practice” case it has been assumed that the intensity of remaining production in this sector can improve by up to 1.5 percent/year faster than in the baseline for thermal energy, and by up to 1 percent/year faster for electricity.

Table 5.4: Activities in the basic chemicals industry

Activity	GAINS code	Unit	Projection method and data sources
Value added	VA_INDCHEM	10 <sup>9</sup> €	IEA macro forecast, correlation with industrial GDP, national studies
Ammonia	PR_AMON	10 <sup>6</sup> tons N	Correlation with sectoral value added
Ethylene	PR_ETHYL	10 <sup>6</sup> tons	Correlation with sectoral value added
Chlorine	PR_CHLOR	10 <sup>6</sup> tons	Correlation with sectoral value added

## 5.4 Non-metallic minerals industry

The most energy-intensive products in this sector are cement and lime production (Table 5.5), which are responsible for 60 to 70 percent of thermal energy use and for 40 to 50 percent of electricity. The forecast of activities is based on historic developments and on correlations with sectoral GDP. The intensity of cement production heavily depends on the share of clinker. In some countries materials replacing clinker (fly ash, blast furnace slag, and puzzolana) are already extensively used as clinker substitutes (compare CEMBUREAU, 1999). For countries where the historic use of clinker substitutes was low, it is assumed that the share will increase in the future autonomously. The penetration of efficiency improvement options in 2005 has been calibrated so that sectoral fuel and electricity consumption is consistent with the IEA statistics. Rates of assumed efficiency improvement up to 2020 rely national studies and adjusted in such a way that total energy consumption match the values given in the IEA WEO 2008 energy projection. Data on energy intensity of the best practices in cement industry are based on Martin *et al.*, 1999; Stubenvoll, 1998. For the “best practice” case it has been assumed that the intensity of remaining production in this sector

can improve by up to 1.5 percent/year faster than in the baseline for thermal energy, and by up to 1 percent/year faster for electricity.

Table 5.5: Activities in the non-metallic minerals industry

Activity	GAINS code	Unit	Projection method and data sources
Value added	VA_INDNMMI	10 <sup>9</sup> €	IEA macro forecast, correlation with industrial GDP, national studies
Cement production	PR_CEM	10 <sup>6</sup> tons	Correlation with sectoral value added
of which clinker	PR_CLINK	10 <sup>6</sup> tons	National studies and forecasts
Lime production	PR_LIME	10 <sup>6</sup> tons	Correlation with sectoral value added

## 5.5 Pulp and paper industry

About 90 to 95 percent of total final energy use in the paper and pulp industry is explained by production of paper and pulp, with a share of electricity of 70 to 75 percent. Activities included for this sector are presented in (Table 5.6). The forecast is based on historic development and on correlation with sectoral GDP projections. It includes an increase in paper recycling.

The penetration of efficiency improvement options in 2005 has been calibrated so that sectoral fuel and electricity consumption is consistent with the IEA statistics. Rates of assumed efficiency improvement up to 2020 rely national studies and adjusted in such a way that total energy consumption match the values given in the IEA WEO 2008 energy projection. Data on energy intensity of production technologies in this sector and on the best practices are based on Nilsson, 1996 and Martin, 2000. For the “best practice” case it has been assumed that the intensity of remaining production in this sector can improve by up to 1.5 percent/year faster than in the baseline for thermal energy, and by up to 1 percent/year faster for electricity.

Table 5.6: Activities in the pulp and paper industry

Activity	GAINS code	Unit	Projection method and data sources
Value added	VA_INDPAP	10 <sup>9</sup> €	IEA macro forecast, correlation with industrial GDP, national studies
Pulp from wood	PR_PULP	10 <sup>6</sup> tons	National studies
Pulp from recovered paper	PR_PULPREC	10 <sup>6</sup> tons	National studies
Paper and paperboard	PR_PAPER	10 <sup>6</sup> tons	Correlation with sectoral value added

## 5.6 Other industries

The five industrial sectors that are presented above are responsible for about two thirds of total final energy use. Remaining energy consumption is considered in GAINS as “Other industries” (INDOTH). Again, base year energy consumption is consistent with the IEA statistics. Baseline rates of improvement of energy intensity correspond to the reference case of the IEA WEO 2008 (IEA, 2008b). For the “best practice” case, a faster improvement with similar rates as for the other sectors is assumed.

## 6 Concluding remarks

The methodology presented in this report has been applied for analysis of options that change energy demand structure and reduce energy consumption for Annex I countries. These options can importantly contribute to the reduction of CO<sub>2</sub> emissions from energy production and use. The methodology allows a comparison of potentials and costs to mitigate emissions of greenhouse gases among countries. Although the method is quite data intensive, in the opinion of the authors it represents a reasonable compromise between the level of detail that is necessary to capture country-specific circumstances that have significant impact on mitigation potentials and costs in a country, and the transparency of the approach. As any other methodology, it has its strengths and limitations, as listed below:

### Strengths:

The GAINS methodology

- includes energy needs at a detailed level. The assessment is based on a bottom-up approach that considers structural and technical features that prevail in a country;
- is based on an extensive literature search;
- includes proven technical possibilities for reducing energy consumption that are available on the international market;
- includes country-specific factors, like differences in existing capital stock, different climate, lifestyles, living space per capita, and different base year efficiency level;
- the assessment reproduces the base year (2005) energy consumption as provided in the IEA statistics. For future years, exogenous projections (including national scenarios) are taken into account as a starting point for the assessment of the further potential for efficiency improvement;
- for a number of countries input data for calculations have been verified by national experts. National experts have employed data sets from their own modelling work or from other national studies to review and modify IIASA's default assumptions. Thus local knowledge was included to the extent possible within the given time.

### Weaknesses and limitations:

- Not all details are available from national sources. Thus for some sectors and energy needs assumptions had to be made.
- Information about costs of efficiency measures was scarce. The current database relies on limited cost information. In many cases cost figures have been derived through appropriate scaling of costs for similar group of consumers.

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